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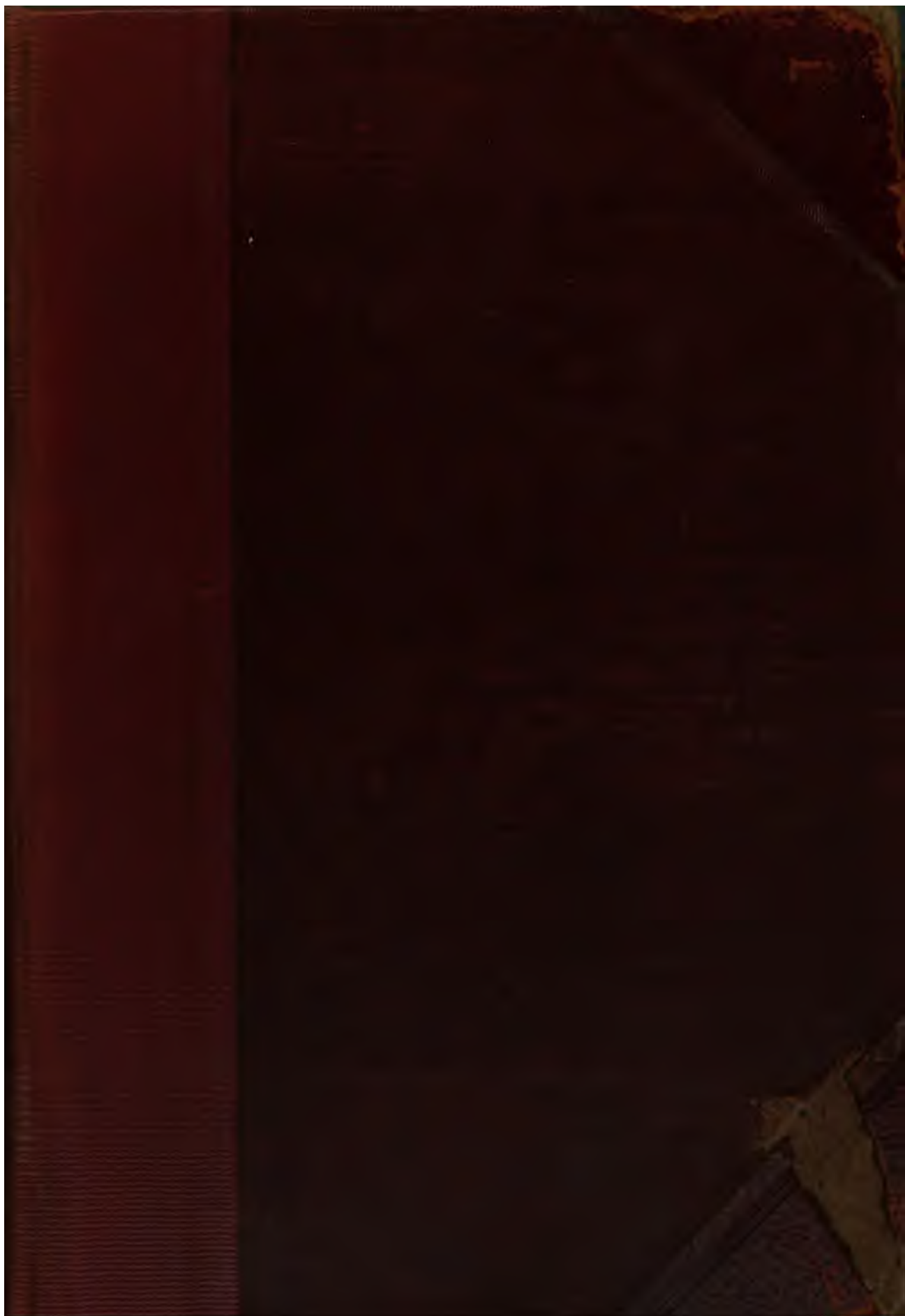
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VOLUME X.
MECHANICAL DRAWING



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Volume X.

MECHANICAL DRAWING

SECTION I.

MECHANICAL DRAWING.

PART I.

The subject of mechanical drawing is of great interest and importance to all mechanics and engineers. Drawing is the method used to show graphically the small details of machinery; it is the language by which the designer speaks to the workman; it is the most graphical way to place ideas and calculations on record. Working drawings take the place of lengthy explanations, either written or verbal. A brief inspection of an accurate, well-executed drawing gives a better idea of a machine than a large amount of verbal description. The better and more clearly a drawing is made, the more intelligently the workman can comprehend the ideas of the designer. A thorough training in this important subject is necessary to the success of everyone engaged in mechanical work. The success of a draftsman depends to some extent upon the quality of his instruments and materials. Beginners frequently purchase a cheap grade of instruments. After they have become expert and have learned to take care of their instruments they discard them for those of better construction and finish. This plan has its advantages, but to do the best work, strong, well-made and finely finished instruments are necessary.

INSTRUMENTS AND MATERIALS.

Drawing Paper. In selecting drawing paper, the first thing to be considered is the kind of paper most suitable for the proposed work. For shop drawings, a manilla paper is frequently used, on account of its toughness and strength, because the drawing is likely to be subjected to considerable hard usage. If a finished drawing is to be made, the best white drawing paper should be obtained, so that the drawing will not fade or become discolored with age. A good drawing paper should be strong, have uniform thickness and surface, should stretch evenly, and should neither repel nor absorb liquids. It should also allow considerable erasing without spoiling the surface, and it should lie smooth when stretched or when ink or colors are used. It is, of

course, impossible to find all of these qualities in any one paper, as for instance great strength cannot be combined with fine surface.

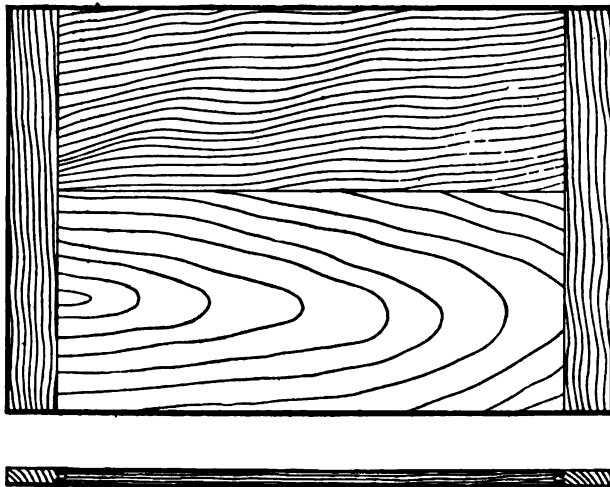
In selecting a drawing paper the kind should be chosen which combines the greatest number of these qualities for the given work. Of the better class Whatman's are considered by far the best. This paper is made in three grades; the *hot pressed* has a smooth surface and is especially adapted for pencil and very fine line drawing, the *cold pressed* is rougher than the hot pressed, has a finely grained surface and is more suitable for water color drawing; the *rough* is used for tinting. The cold pressed does not take ink as well as the hot pressed, but erasures do not show as much on it, and it is better for general work. There is but little difference in the two sides of Whatman's paper, and either can be used. This paper comes in sheets of standard sizes as follows:—

Cap,	13 × 17 inches.	Elephant,	23 × 28 inches.
Demy,	15 × 20 "	Columbia,	23 × 34 "
Medium,	17 × 22 "	Atlas,	26 × 34 "
Royal,	19 × 24 "	Double Elephant,	27 × 40 "
Super-Royal,	19 × 27 "	Antiquarian,	31 × 53 "
Imperial,	22 × 30 "	Emperor,	48 × 68 "

The usual method of fastening paper to a drawing board is by means of thumb tacks or small one-ounce copper or iron tacks. In fastening the paper by this method first fasten the upper left hand corner and then the lower right pulling the paper taut. The other two corners are then fastened, and sufficient number of tacks are placed along the edges to make the paper lie smoothly. For very fine work the paper is usually stretched and glued to the board. To do this the edges of the paper are first turned up all the way round, the margin being at least one inch. The whole surface of the paper included between these turned up edges is then moistened by means of a sponge or soft cloth and paste or glue is spread on the turned up edges. After removing all the surplus water on the paper, the edges are pressed down on the board, commencing at one corner. During this process of laying down the edges, the paper should be stretched slightly by pulling the edges towards the edges of the drawing board. The drawing board is then placed horizontally and left to dry. After the paper has become dry it will be found to be as smooth and tight as a

drum head. If, in stretching, the paper is stretched too much it is likely to split in drying. A slight stretch is sufficient.

Drawing Board. The size of the drawing board depends upon the size of paper. Many draftsmen, however, have several boards of various sizes, as they are very convenient. The drawing board is usually made of soft pine, which should be well seasoned and straight grained. The grain should run lengthwise of the board, and at the two ends there should be pieces about $1\frac{3}{4}$ or 2 inches wide fastened to the board by nails or screws. These end pieces should be perfectly straight for accuracy in using the T-square. Frequently the end pieces are fastened by a glued



DRAWING BOARD.

matched joint, nails and screws being also used. Two cleats on the bottom extending the whole width of the board, will reduce the tendency to warp, and make the board easier to move as they raise it from the table.

Thumb Tacks. Thumb tacks are used for fastening the paper to the drawing board. They are usually made of steel either pressed into shape, as in the cheaper grades, or made with a head of German silver with the point screwed and riveted to it. They are made in various sizes and are very convenient as they can be easily removed from the board. For most work however,

draftsmen use small one-ounce copper or iron tacks, as they can be forced flush with the drawing paper, thus offering no obstruction to the T-square. They also possess the advantage of cheapness.

Pencils. In pencilling a drawing the lines should be very fine and light. To obtain these light lines a hard lead pencil must be used. Lead pencils are graded according to their hardness, and are numbered by using the letter H. In general a lead pencil of 5H (or HHHHH) or 6H should be used. A softer pencil, 4H,



Fig. 1.

is better for making letters, figures and points. A hard lead pencil should be sharpened as shown in Fig. 1. The wood is cut away so that about $\frac{1}{4}$ or $\frac{3}{8}$ inch of lead projects. The lead can then be sharpened to a chisel edge by rubbing it against a bit of sand paper or a fine file. It should be ground to a chisel edge and the corners slightly rounded. In making the straight lines the chisel edge should be used by placing it against the T-square or triangle, and because of the chisel edge

the lead will remain sharp much longer than if sharpened to a point. This chisel edge enables the draftsman to draw a fine line exactly through a given point. If the drawing is not to be inked, but is made for tracing or for rough usage in the shop, a softer pencil, 3H or 4H, may be used, as the lines will then be somewhat thicker and heavier. The lead for compasses may also be sharpened to a point although some draftsmen prefer to use a chisel edge in the compasses as well as for the pencil.

In using a very hard lead pencil, the chisel edge will make a deep depression in the paper if much pressure is put on the pencil. As this depression cannot be erased it is much better to press lightly on the pencil.

Erasers. In making drawings, but little erasing should be necessary. However, in case this is necessary, a soft rubber should be used. In erasing a line or letter, great care must be exercised or the surrounding work will also become erased. To prevent this, some draftsmen cut a slit about 3 inches long and $\frac{1}{8}$ to $\frac{1}{4}$ inch wide in a card as shown in Fig. 2. The card is then

placed over the work and the line erased without erasing the rest of the drawing. An erasing shield of a form similar to that shown in Fig. 3 is very convenient, especially in erasing letters. It is made of thin sheet metal and is clean and durable.

For cleaning drawings, a sponge rubber may be used. Bread

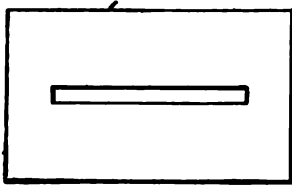


Fig. 2.

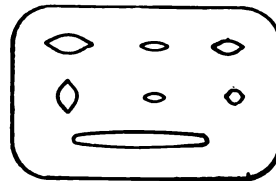


Fig. 3.

crumbs are also used for this purpose. To clean the drawing scatter *dry* bread crumbs over it and rub them on the surface with the hand.

T-Square. The T-square consists of a thin straight edge



Fig. 4.

called the blade, fastened to a head at right angles to it. It gets its name from the general shape. T-squares are made of various materials, wood being the most commonly used. Fig. 4 shows an ordinary form of T-square which is adapted to most work. In Fig. 5 is shown a T-square with edges made of ebony or mahogany, as these woods are much harder than pear wood or maple, which is generally used. The head is formed so as to fit against the left-hand edge of the drawing board, while the blade extends over the surface. It is desirable to have the blade of the T-square form a right angle with the head, so that the lines drawn with the T-square will be at right angles to the left-hand edge of the board. This, however, is not absolutely necessary, because the lines drawn with the T-square are always with reference to one edge of the

board only, and if this edge of the board is straight, the lines drawn with the T-square will be parallel to each other. The T-square should never be used except with the left-hand edge of the board, as it is almost impossible to find a drawing board with the edges parallel or at right angles to each other.

The T-square with an adjustable head is frequently very convenient, as it is sometimes necessary to draw lines parallel to each



Fig. 5.

other which are not at right angles to the left-hand edge of the board. This form of T-square is similar to the ordinary T-square already described, but the head is swiveled so that it may be clamped at any desired angle. The ordinary T-square as shown

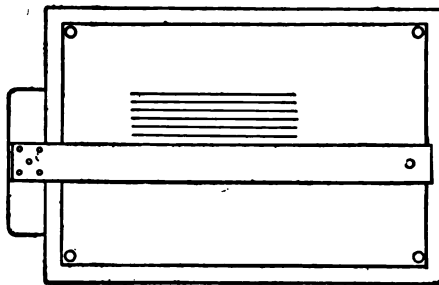


Fig. 6.

in Figs. 4 and 5 is, however, adapted to almost any class of drawing.

Fig. 6 shows the method of drawing parallel horizontal lines with the T-square. With the head of the T-square in contact with the left-hand edge of the board, the lines may be

drawn by moving the T-square to the desired position. In using the T-square the upper edge should always be used for drawing as the two edges may not be exactly parallel and straight, and also it is more convenient to use this edge with the triangles. If it is necessary to use a straight edge for trimming drawings or cutting the paper from the board, the lower edge of the T-square should be used so that the upper edge may not be marred.

For accurate work it is absolutely necessary that the working edge of the T-square should be exactly straight. To test the

straightness of the edge of the T-square, two T-squares may be placed together as shown in Fig. 7. This figure shows plainly that the edge of one of the T-squares is crooked. This fact, however, does not prove that either one is straight, and for this determination a third blade must be used and tried with the two given T-squares successively.

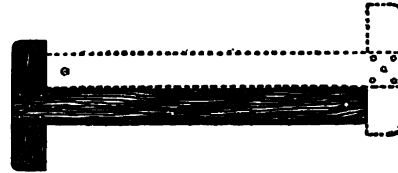
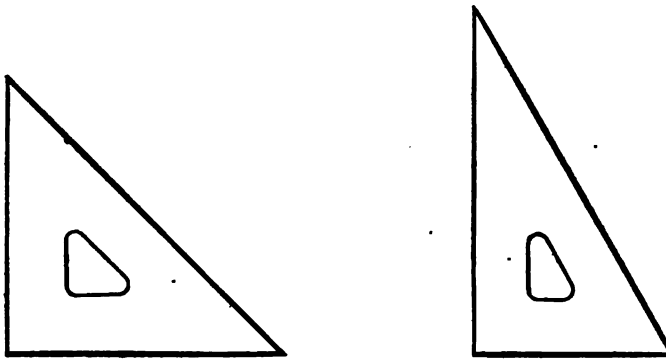


Fig. 7.

Triangles. Triangles are made of various substances such as wood, rubber, celluloid and steel. Wooden triangles are cheap but are likely to warp and get out of shape. The rubber triangles are frequently used, and are in general satisfactory. The transparent celluloid triangle is, however, extensively used on account of its transparency, which enables the draftsmen to see the work already done even when covered with the triangle. In using a rubber or celluloid triangle take care that it lies perfectly flat or



TRIANGLES.

is hung up when not in use ; when allowed to lie on the drawing board with a pencil or an eraser under one corner it will become warped in a short time, especially if the room is hot or the sun happens to strike the triangle.

Triangles are made in various sizes, and many draftsmen have several constantly on hand. A triangle from 6 to 8 inches on a side will be found convenient for most work, although there are many cases where a small triangle measuring about 4 inches

on a side will be found useful. Two triangles are necessary for every draftsman, one having two angles of 45 degrees each and one a right angle; and the other having one angle of 60 degrees, one of 30 degrees and one of 90 degrees.

The value of the triangle depends upon the accuracy of the angles and the straightness of the edges. To test the accuracy of

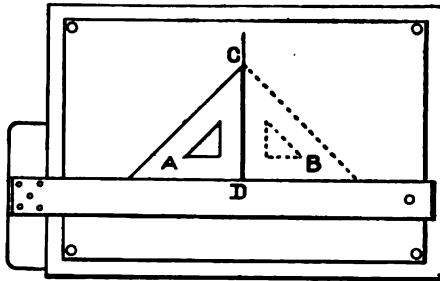


Fig. 8.

the right angle of a triangle, place the triangle with the lower edge resting on the edge of the T-square, as shown in Fig. 8. Now draw the line C D, which should be perpendicular to the edge of the T-square. The same triangle should then

be placed in the position shown at B. If the right angle of the triangle is exactly 90 degrees the left-hand edge of the triangle should exactly coincide with the line C D.

To test the accuracy of the 45-degree triangles, first test the right angle then place the triangle with the lower edge resting on the working edge of the T-square, and draw the line E F as shown in Fig. 9. Now without moving the T-square place the triangle so that the other 45-degree angle is in the position occupied by the first. If the two 45-degree angles coincide they are accurate.

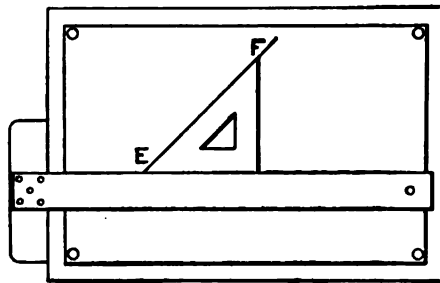


Fig. 9.

Triangles are very convenient in drawing lines at right angles to the T-square. The method of doing this is shown in Fig. 10. Triangles are also used in drawing lines at an angle with the horizontal, by placing them on the board as shown in Fig. 11. Suppose the line E F (Fig. 12) is drawn at any angle, and we wish to draw a line through the point P parallel to it.

First place one of the triangles as shown at A, having one edge coinciding with the given line. Now take the other triangle and place one of its edges in contact with the bottom edge of triangle A. Holding the triangle B firmly with the left hand the triangle A may be slipped along to the right or to the left until the edge of the triangle reaches the point P. The line M N may then be drawn along the edge of the triangle passing through the point P. In place of the triangle B any straight edge such as a T-square may be used.

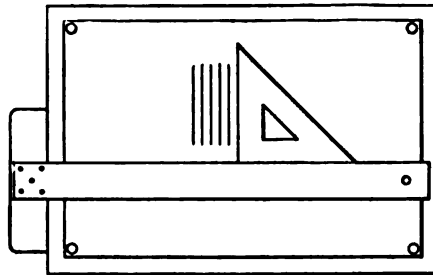


Fig. 10.

A line can be drawn perpendicular to another by means of the triangles as follows. Let E F (Fig. 13) be the given line, and suppose we wish to draw a line perpendicular to E F through the point D. Place the longest side of one of the triangles so that it coincides with the line E F, as the triangle is shown in position at A.

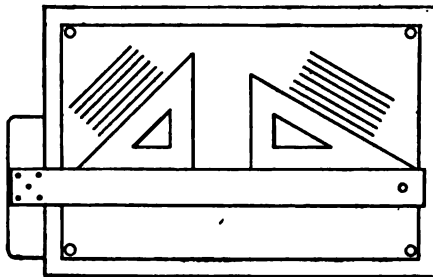


Fig. 11.

Place the other triangle (or any straight edge) in the position of the triangle as shown at B, one edge resting against the edge of the triangle A. Then holding B with the left hand, place the tri-

angle A in the position shown at C, so that the longest side passes through the point D. A line can then be drawn through the point D perpendicular to E F.

In previous figures we have seen how lines may be drawn making angles of 30, 45, 60 and 90 degrees with the horizontal. If it is desired to draw lines forming angles of 15 and 75 degrees the triangles may be placed as shown in Fig. 14.

In using the triangles and T-square almost any line may be drawn. Suppose we wish to draw a rectangle having one side

horizontal. First place the T-square as shown in Fig. 15. By moving the T-square up or down, the sides A B and D C may be drawn, because they are horizontal and parallel. Now place one of the triangles resting on the T-square as shown at E, and having the left-hand edge passing through the point D. The vertical

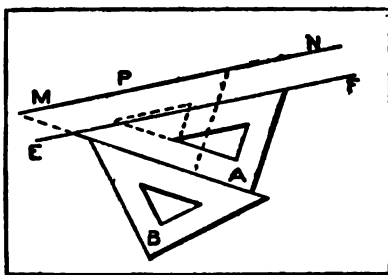


Fig. 12.

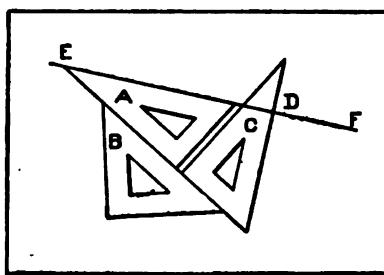


Fig. 13.

line D A may be drawn, and by sliding the triangle along the edge of the T-square to the position F the line B C may be drawn by using the same edge. These positions are shown dotted in Fig. 15.

If the rectangle is to be placed in some other position on the drawing board, as shown in Fig. 16, place the 45-degree triangle

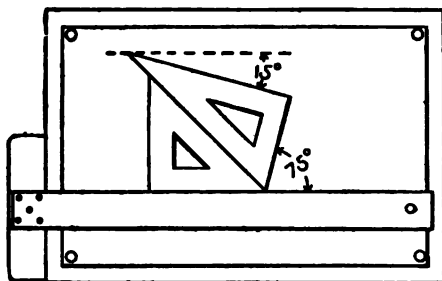


Fig. 14.

F so that one edge is parallel to or coincides with the side D C. Now holding the triangle F in position place the triangle H so that its upper edge coincides with the lower edge of the triangle F. By holding H in position and sliding the triangle F

along its upper edge, the sides A B and D C may be drawn. To draw the sides A D and B C the triangle should be used as shown at E.

Compasses. Compasses are used for drawing circles and arcs of circles. They are made of various materials and in various sizes. The cheaper class of instruments are made of brass, but they are unsatisfactory on account of the odor and the tendency to tarnish. The best material is German silver. It does not soil

readily, it has no odor, and is easy to keep clean. Aluminum instruments possess the advantage of lightness, but on account of the soft metal they do not wear well.

The compasses are made in the form shown in Figs. 17 and 18. Pencil and pen points are provided, as shown in Fig. 17. Either pen or pencil may be inserted in one leg by means of a shank and socket. The other leg is fitted with a needle point which is placed at the center of the circle. In most instruments the needle point is separate, and is made of a piece of round steel wire having a square shoulder at one or both ends. Below this shoulder the needle point projects. The needle is made in this form so that the hole in the paper may be very minute.

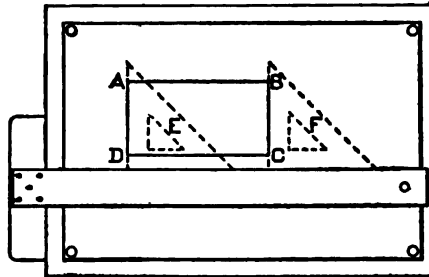


Fig. 15.

In some instruments lock nuts are used to hold the joint firmly in position. These lock nuts are thin discs of steel, with

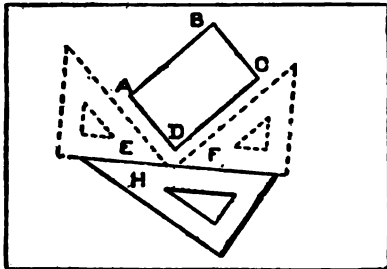


Fig. 16.

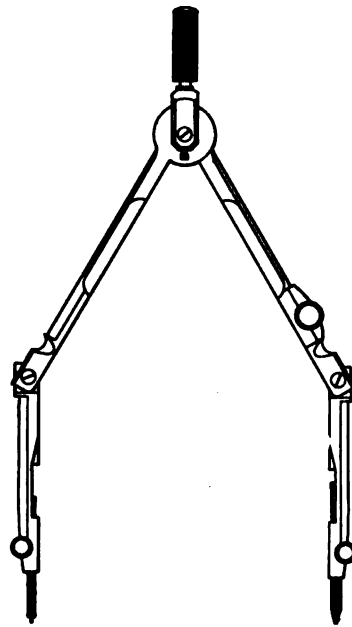
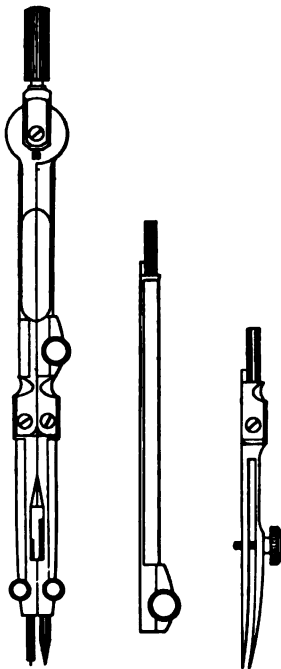
notches for using a wrench or forked key. Fig. 19 shows the detail of the joint of high grade instruments. Both legs are alike at the joint, and two pivoted screws are inserted in the yoke. This permits ample movement of the legs, and at the same time gives the proper stiffness. The flat surface of one of

the legs is faced with steel, the other being of German silver, in order that the rubbing parts may be of different metals. Small set screws are used to prevent the pivoted screws from turning in the yoke. The contact surfaces of this joint are made circular to exclude dust and dirt and to prevent rusting of the steel face.

Figs. 20, 21, and 22 show the detail of the socket; in some

instruments the shank and socket are pentagonal, as shown in Fig. 20. The shank enters the socket loosely, and is held in place by means of the screw. Unless used very carefully this arrangement is not durable because the sharp corners soon wear, and the pressure on the set screw is not sufficient to hold the shank firmly in place.

In Fig. 21 is shown another form of shank. This is round, having a flat top. A set screw is also used to hold this in position. A still better form of socket is shown in Fig. 22; the hole



is made tapered and is circular. The shank fits accurately, and is held in perfect alignment by a small steel key. The clamping screw is placed upon the side, and keeps the two portions of the split socket together.

Figs. 17 and 18 show that both legs of the compasses are jointed in order that the lower part of the legs may be perpendicular to the paper while drawing circles. In this way the needle point makes but a small hole in the paper, and both nibs of

the pen will press equally on the paper. In pencilling circles it is not as necessary that the pencil should be kept vertical; it is a good plan, however, to learn to use them in this way both in pencilling and inking. The compasses should be held loosely between the thumb and forefinger. If the needle point is sharp, as it should be, only a slight pressure will be required to keep it in place. While drawing the circle, incline the compasses slightly in the direction of revolution and press lightly on the pencil or pen.

In removing the pencil or pen, it should be pulled out straight. If bent from side to side the socket will become enlarged and the shank worn; this will render the instrument inaccurate. For drawing large circles the lengthening bar shown in Fig. 17 should be used. When using the lengthening bar the

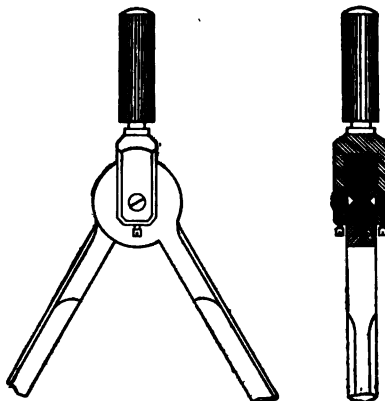


Fig. 19.



Fig. 20.



Fig. 21.

needle point should be steadied with one hand and the circle described with the other.

Dividers. Dividers, shown in Fig. 23, are made similar to the compasses. They are used for laying off distances on the drawing, either from scales or from other parts of the drawing. They



Fig. 22.

may also be used for dividing a line into equal parts. When dividing a line into equal parts the dividers should be turned in the opposite direc-

tion each time, so that the moving point passes alternately to the right and to the left. The instrument can then be operated readily with one hand. The points of the dividers should be very sharp so that the holes made in the paper will be small. If large holes are made in the paper, and the distances between

the points are not exact, accurate spacing cannot be done. Sometimes the compasses are furnished with steel divider points in addition to the pen and pencil points. The compasses may then be used either as dividers or as compasses. Many draftsmen use a *needle point* in place of dividers for making measurements from a scale. The eye end of a needle is first broken off and the needle then forced into a small handle made of a round piece of soft pine. This instrument is very convenient for indicating the intersection of lines and marking off distances.



Fig. 23.

Bow Pen and Bow Pencil. Ordinary large compasses are too heavy to use in making small circles, fillets, etc. The leverage of the long leg is so great that it is very difficult to draw small circles accurately. For this reason the bow compasses shown in Figs. 24 and 25 should be used on all arcs and circles having a radius of less than three-quarters inch. The bow compasses are also convenient for duplicating small circles such as those which represent boiler tubes, bolt holes, etc., since there is no tendency to slip.

The needle point must be adjusted to the same length as the pen or pencil point if very small circles are to be drawn. The adjustment for altering the radius of the circle can be made by turning the nut. If the change in radius is considerable the points should be pressed together to remove the pressure from the nut which can then be turned in either direction with but little wear on the threads.

Fig. 26 shows another bow instrument which is frequently used in small work in place of the dividers. It has the advantage of retaining the adjustment.

Drawing Pen. For drawing straight lines and curves that are not arcs of circles, the line pen (sometimes called the ruling pen) is used. It consists of two blades of steel fastened to a handle as shown in Fig. 27. The distance between the pen points can be adjusted by the thumb screw, thus regulating the width of line to be drawn. The blades are given a slight curvature so that there will be a cavity for ink when the points are close together.

The pen may be filled by means of a common steel pen or with the quill which is provided with some liquid inks. The pen should not be dipped in the ink because it will then be necessary to wipe the outside of the blades before use. The ink should fill the pen to a height of about $\frac{1}{4}$ or $\frac{3}{8}$ inch; if too much ink is placed in the pen it is likely to drop out and spoil the drawing. Upon finishing the work the pen should be carefully wiped with

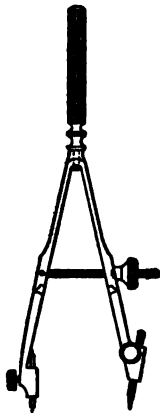


Fig. 24.

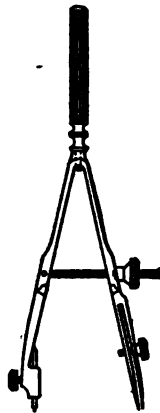


Fig. 25.

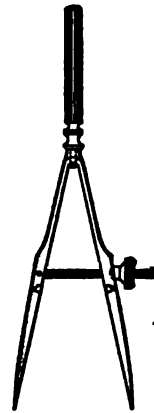


Fig. 26.

chamois or a soft cloth, because most liquid inks corrode the steel.

In using the pen, care should be taken that both blades bear equally on the paper. If the points do not bear equally the line will be ragged. If both points touch, and the pen is in good condition the line will be smooth. The pen is usually inclined slightly in the direction in which the line is drawn. The pen



Fig. 27.

should *touch* the triangle or T-square which serve as guides, but it should not be pressed against them because the lines will then be uneven. The points of the pen should be close to the edge of the triangle or T-square, but should not touch it.

To Sharpen the Drawing Pen. After the pen has been used for some time the points become worn, and it is impossible

to make smooth lines. This is especially true if rough paper is used. The pen can be put in proper condition by sharpening it. To do this take a small, flat, close-grained oil-stone. The blades should first be screwed together, and the points of the pen can be given the proper shape by drawing the pen back and forth over the stone changing the inclination so that the shape of the ends will be parabolic. This process dulls the points but gives them the proper shape, and makes them of the same length.

To sharpen the pen, separate the points slightly and rub one of them on the oil-stone. While doing this keep the pen at an angle of from 10 to 15 degrees with the face of the stone, and give it a slight twisting movement. This part of the operation requires great care as the shape of the ends must not be altered. After the pen point has become fairly sharp the other point should be ground in the same manner. All the grinding should be done on the *outside* of the blades. The burr should be removed from the inside of the blades by using a piece of leather or a piece of pine wood.

Ink should now be placed between the blades and the pen tried. The pen should make a smooth line whether fine or heavy, but if it does not the grinding must be continued and the pen tried frequently.

Ink. India ink is always used for drawing as it makes a permanent black line. It may be purchased in solid stick form or as a liquid. The liquid form is very convenient as much time is saved, and all the lines will be of the same color; the acid in the ink, however, corrodes steel and makes it necessary to keep the pen perfectly clean.

Some draftsmen prefer to use the India ink which comes in stick form. To prepare it for use, a little water should be placed in a saucer and one end of the stick placed in it. The ink is ground by giving it a twisting movement. When the water has become black and slightly thickened, it should be tried. A heavy line should be made on a sheet of paper and allowed to dry. If the line has a grayish appearance, more grinding is necessary. After the ink is thick enough to make a good black line, the grinding should cease, because very thick ink will not flow freely from the pen. If, however, the ink has become too

thick, it may be diluted with water. After using, the stick should be wiped dry to prevent crumbling. It is well to grind the ink in small quantities as it does not dissolve readily if it has once become dry. If the ink is kept covered it will keep for two or three days.

Scales. Scales are used for obtaining the various measurements on drawings. They are made in several forms, the most convenient being the flat with beveled edges and the triangular. The scale is usually a little over 12 inches long and is graduated for a distance of 12 inches. The triangular scale shown in Fig. 28 has six surfaces for graduations, thus allowing many graduations on the same scale.

The graduations on the scales are arranged so that the drawings may be made in any proportion to the actual size. For mechanical work, the common divisions are multiples of two.



Fig. 28.

Thus we make drawings full size, half size, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, $\frac{1}{64}$, etc. If a drawing is $\frac{1}{4}$ size, 3 inches equals 1 foot, hence 8 inches is divided into 12 equal parts and each division represents one inch. If the smallest division on a scale represents $\frac{1}{16}$ inch, the scale is said to read to $\frac{1}{16}$ inch.

Scales are often divided into $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{30}$, $\frac{1}{40}$, etc., for architects, civil engineers, and for measuring on indicator cards.

The scale should never be used for drawing lines in place of triangles or T-square.

Protractor. The protractor is an instrument used for laying off and measuring angles. It is made of steel, brass, horn and paper. If made of metal the central portion is cut out as shown in Fig. 29, so that the draftsman can see the drawing. The outer edge is divided into degrees and tenths of degrees. Sometimes the graduations are very fine. In using a protractor a very sharp hard pencil should be used so that the lines will be fine and accurate.

The protractor should be placed so that the given line (pro-

duced if necessary) coincides with the two O marks. The center of the circle being placed at the point through which the desired line is to be drawn. The division can then be marked with the pencil point or needle point.

Irregular Curve. One of the conveniences of a draftsman's

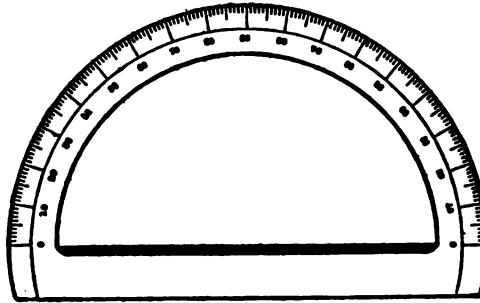
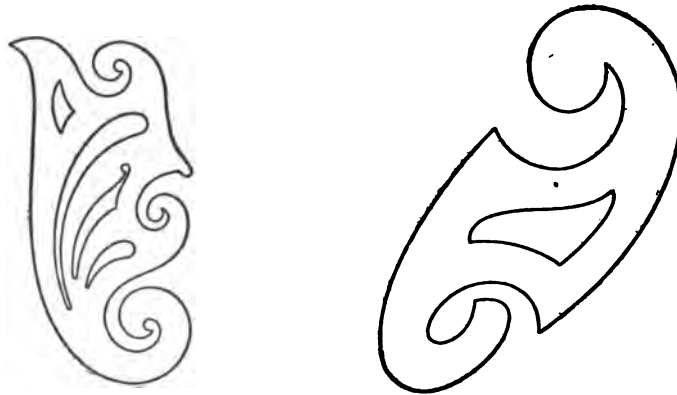


Fig. 29.

outfit is the French or irregular curve. It is made of wood, hard rubber or celluloid, the last named material being the best. It is made in various shapes, two of the most common being



• Fig. 30.

shown in Fig. 30. This instrument is used for drawing curves other than arcs of circles, and both pencil and line pen can be used.

To draw the curve, a series of points is first located and then the curve drawn passing through them by using the part of the irregular curve that passes through several of them. The

curve is shifted for this work from one position to another. It frequently facilitates the work and improves its appearance to draw a free hand pencil curve through the points and then use the irregular curve, taking care that it always fits at least *three* points.

In inking the curve, the blades of the pen must be kept

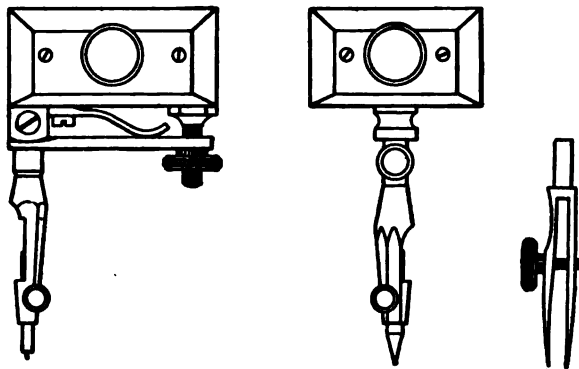


Fig. 31.

tangent to the curve, thus necessitating a continual change of direction.

Beam Compasses. The ordinary compasses are not large enough to draw circles having a diameter greater than about 8 or 10 inches. A convenient instrument for larger circles is found in the beam compasses shown in Fig. 31. The two parts called channels carrying the pen or pencil and the needle point are clamped to a wooden beam; the distance between them being equal to the radius of the circle. Accurate adjustment is obtained by means of a thumb nut underneath one of the channel pieces.

LETTERING.

No mechanical drawing is finished unless all headings, titles and dimensions are lettered in plain, neat type. Many drawings are accurate, well-planned and finely executed but do not present a good appearance because the draftsman did not think it worth while to letter well. Lettering requires time and patience; and if one wishes to letter rapidly and well he must practice.

Usually a beginner cannot letter well, and in order to produce a satisfactory result, considerable practice is necessary. Many

think it a good plan to practice lettering before commencing a drawing. A good writer does not always letter well; a poor writer need not be discouraged and think he can never learn to make a neatly lettered drawing.

In making large letters for titles and headings it is often necessary to use drawing instruments and mechanical aids. The small letters, such as those used for dimensions, names of materials, dates, etc., should be made free hand.

There are many styles of letters used by draftsmen. For titles, large Roman capitals are frequently used, although Gothic and block letters also look well and are much easier to make.



Fig. 32.

Almost any neat letter free from ornamentation is acceptable in the regular practice of drafting. Fig. 32 shows the alphabet of vertical Gothic capitals. These letters are neat, plain and easily made. The inclined or italicized Gothic type is shown in Fig. 33. This style is also easy to construct, and possesses the advantage that a slight difference in inclination is not apparent. If the vertical lines of the vertical letters incline slightly the inaccuracy is very noticeable.

The curves of the inclined Gothic letters such as those in the *B*, *C*, *G*, *J*, etc., are somewhat difficult to make free hand, especially if the letters are about one-half inch high. In the alphabet shown in Fig. 34, the letters are made almost wholly of

straight lines, the corners only being curved. These letters are very easy to make and are clear cut.

The first few plates of this work will require no titles; the only lettering being the student's name, together with the date and plate number. Later, the student will take up the subject of

A B C D E F G H I J
K L M N O P Q R
S T U V W X Y Z

Fig. 33.

lettering again in order to letter titles and headings for drawings showing the details of machines. For the present, however, inclined Gothic capitals will be used.

To make the inclined Gothic letters, first draw two parallel lines having the distance between them equal to the desired height of the letters. If two sizes of letters are to be used, the smaller should be about two-thirds as high as the larger. For the letters

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 0

Fig. 34.

to be used on the first plates, draw two parallel lines $\frac{5}{32}$ inch apart. This is the height for the letters of the date, name, also the plate number, and should be used on all plates throughout this work, unless other directions are given.

In constructing the letters, they should extend fully to these lines, both at the top and bottom. They should not fall short of

the guide lines nor extend beyond them. As these letters are inclined they will look better if the inclination is the same for all. As an aid to the beginner, he can draw light pencil lines, about $\frac{1}{4}$ inch apart, forming the proper angle with the parallel lines already drawn. The inclination is often made about 70 degrees; but as a 60-degree triangle is at hand, it may be used. To draw these lines place the 60-degree triangle on the T-square as shown in Fig. 86. In making these letters the 60-degree lines will be found a great aid as a large proportion of the back or side lines have this inclination.

Capital letters such as *E*, *F*, *P*, *T*, *Z*, etc., should have the top lines coincide with the upper horizontal guide line. The bottom lines of such letters as *D*, *E*, *L*, *Z*, etc., should coincide with the lower horizontal guide line. If these lines do not coincide with the guide lines the words will look uneven. Letters, of which *C*, *G*, *O*, and *Q*, are types, can be formed of curved lines or of straight lines. If made of curved lines, they should have a little greater height than the guide lines to prevent their appearing smaller than the other letters. In this work they can be made of straight lines with rounded corners as they are easily constructed and the student can make all letters of the same height.

To construct the letter *A*, draw a line at an angle of 60 degrees to the horizontal and use it as a center line. Then from the intersection of this line and the upper horizontal line drop a vertical line to the lower guide line. Draw another line from the vertex meeting the lower guide line at the same distance from the center line. The cross line of the *A* should be a little below the center. The *V* is an inverted *A* without the cross line. For the letter *M*, the side lines should be parallel and about the same distance apart as are the horizontal lines. The side lines of the *W* are not parallel but are farther apart at the top. The *J* is not quite as wide as such letters as *H*, *E*, *N*, *R*, etc. To make a *Y*, draw the center line 60 degrees to the horizontal; the diverging lines are similar to those of the *V* but are shorter and form a larger angle. The diverging lines should meet the center line a little below the middle.

The lower-case letters are shown in Fig. 85. In such letters

as *m*, *n*, *p*, *r*, etc., make the corners sharp and not rounding. The letters *a*, *b*, *c*, *e*, *g*, *o*, *p*, *q*, should be full and rounding. The figures (see Fig. 32) are made as in writing — except the 4, 6, 8 and 9.

The Roman numerals are made of straight lines as they are largely made up of *I*, *V* and *X*.

At first the copy should be followed closely and the letters drawn in pencil. For a time, the inclined guide lines may be used,

abcdefghijklmnopqrstuvwxyz

Fig. 35.

but after the proper inclination becomes firmly fixed in mind they should be abandoned. The horizontal lines are used at all times by most draftsmen. After the student has had considerable practice, he can construct the letters in ink without first using the pencil. Later in the work, when the student has become proficient in the simple inclined Gothic capitals, the vertical, block and Roman alphabets should be studied.

PLATES.

To lay out a sheet of paper for the plates of this work, the sheet, A B G F, (Fig. 36) is placed on the drawing board 2 or 3 inches from the left-hand edge which is called the *working edge*. If placed near the left-hand edge, the T-square and triangles can be used with greater firmness and the horizontal lines drawn with the T-square will be more accurate. In placing the paper on the board, always true it up according to the long edge of the sheet. First fasten the paper to the board with thumb tacks, using at least 4 — one at each corner. If the paper has a tendency to curl it is better to use 6 or 8 tacks, placing them as shown in Fig. 36. Thumb tacks are commonly used; but many draftsmen prefer one-ounce tacks as they offer less obstruction to the T-square and triangles.

After the paper is fastened in position, find the center of the

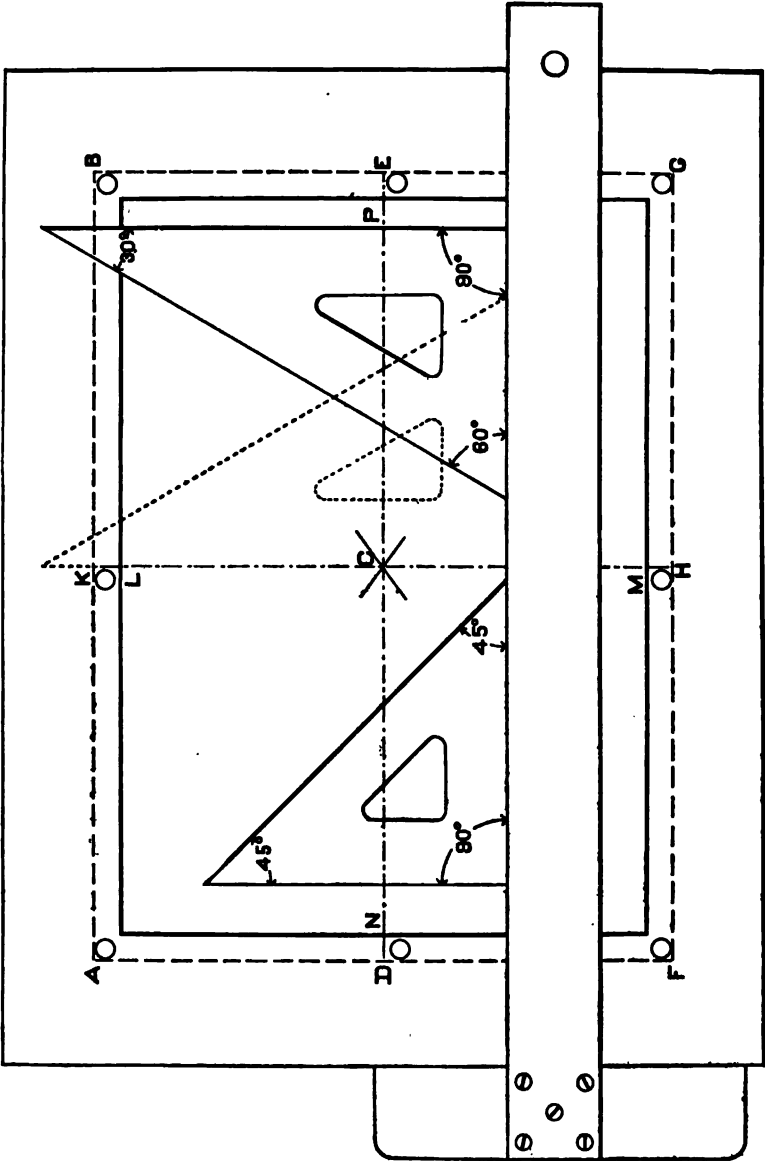


Fig. 36.

sheet by placing the T-square so that its upper edge coincides with the diagonal corners A and G and then with the corners F and B, drawing short pencil lines intersecting at C. Now place the T-square so that its upper edge coincides with the point C and draw the dot and dash line D E. With the T-square and one of the triangles (shown dotted) in the position shown in Fig. 36, draw the dot and dash line H C K. In case the drawing board is large enough, the line C H can be drawn by moving the T-square until it is entirely off the drawing. If the board is small, produce (extend) the line K C to H by means of the T-square or edge of a triangle. In this work always move the pencil from the left to the right or from the bottom upward; never (except for some particular purpose) in the opposite direction.

After the center lines are drawn measure off 5 inches above and below the point C on the line H C K. These points L and M may be indicated by a light pencil mark or by a *slight* puncture of one of the points of the dividers. Now place the T-square against the left-hand edge of the board and draw horizontal pencil lines through L and M.

Measure off 7 inches to the left and right of C on the center line D C E and draw pencil lines through these points (N and P) perpendicular to D E. We now have a rectangle 10 inches by 14 inches, in which all the exercises and figures are to be drawn. The lettering of the student's name and address, date, and plate number are to be placed *outside* of this rectangle in the $\frac{1}{4}$ -inch margin. In all cases lay out the plates in this manner and keep the center lines D E and K H as a basis for the various figures. The border line is to be inked with a heavy line when the drawing is inked.

Pencilling. In laying out plates, all work is first done in pencil and afterward inked or traced on tracing cloth. The first few plates of this course are to be done in pencil and then inked; later the subject of tracing and the process of making blue prints will be taken up. Every beginner should practice with his instruments until he can use them with accuracy and skill, and until he understands thoroughly what instrument should be used for making a given line. To aid the beginner in this work, the first three plates of this course are designed to give the student practice; they do

not involve any problems and none of the work is difficult. The student is strongly advised to draw these plates two or three times before making the one to be sent to us for correction. Diligent practice is necessary at first; especially on *PLATE I* as it involves an exercise in lettering.

PLATE I.

Pencilling. To draw *PLATE I*, take a sheet of drawing paper at least 11 inches by 15 inches and fasten it to the drawing board as already explained. Find the center of the sheet and draw fine pencil lines to represent the lines D E and H K of Fig. 36. Also draw the border lines L, M, N and P.

Now measure $\frac{3}{8}$ inch above and below the horizontal center line and, with the T-square, draw lines through these points. These lines will form the lower lines D C of *Figs. 1* and *2* and the top lines A B of *Figs. 3* and *4*. Measure $\frac{3}{8}$ inch to the right and left of the vertical center line; and through these points, draw lines parallel to the center line. These lines should be drawn by placing the triangle on the T-square as shown in Fig. 36. The lines thus drawn, form the sides B C of *Figs. 1* and *3* and the sides A D of *Figs. 2* and *4*. Next draw the line A B A B with the T-square, $4\frac{1}{2}$ inches above the horizontal center line. This line forms the top lines of *Figs. 1* and *2*. Now draw the line D C D C $4\frac{1}{2}$ inches below the horizontal center line. The rectangles of the four figures are completed by drawing vertical lines $6\frac{1}{2}$ inches from the vertical center line. We now have four rectangles each $6\frac{1}{2}$ inches long and $4\frac{1}{2}$ inches wide.

Fig. 1 is an exercise with the line pen and T-square. Divide the line A D into divisions each $\frac{1}{4}$ inch long, making a fine pencil point or *slight* puncture at each division such as E, F, G, H, I, etc. Now place the T-square with the head at the left-hand edge of the drawing board and through these points draw light pencil lines extending to the line B C. In drawing these lines be careful to have the pencil point pass *exactly* through the division marks so that the lines will be the same distance apart. Start each line in the line A D and do not fall short of the line B C or run over it. Accuracy and neatness in pencilling insure an accurate drawing. Some beginners think that they can correct inaccuracies while

inking; but experience soon teaches them that they cannot do so.

Fig. 2 is an exercise with the line pen, T-square and triangle. First divide the lower line D C of the rectangle into divisions each $\frac{1}{4}$ inch long and mark the points E, F, G, H, I, J, K, etc., as in *Fig. 1*. Place the T-square with the head at the left-hand edge of the drawing board and the upper edge in about the position shown in *Fig. 36*. Place either triangle with one edge on the upper edge of the T-square and the 90-degree angle at the left. Now draw fine pencil lines from the line D C to the line A B passing through the points E, F, G, H, I, J, K, etc. To do this keep the T-square

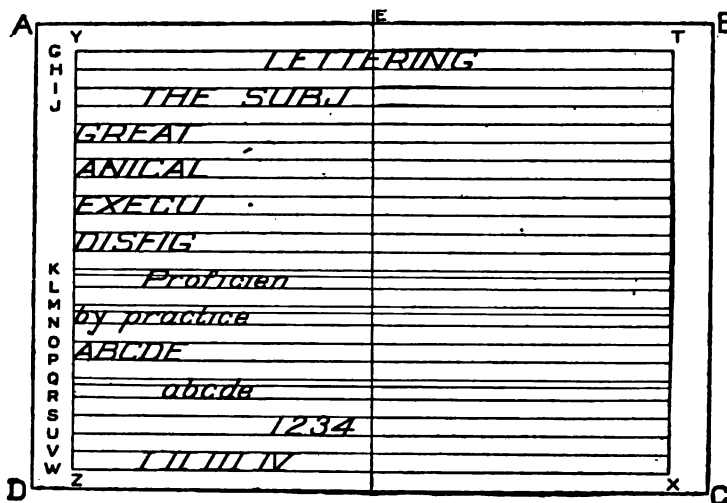


Fig. 37.

rigid and slide the triangle toward the right, being careful to have the edge coincide with the division marks in succession.

Fig. 3 is an exercise with the line pen, T-square and 45-degree triangle. First lay off the distances A E, E F, F G, G H, H I, I J, J K, etc., each $\frac{1}{4}$ inch long. Then lay off the distances B L, L M, M N, N O, O P, P Q, Q R, etc., also $\frac{1}{4}$ inch long. Place the T-square so that the upper edge will be below the line D C of *Fig. 3*. With the 45-degree triangle draw lines from A D and D C to the points E, F, G, H, I, J, K, etc., as far as the point B. Now draw lines from D C to the points L, M, N, O, P, Q, R, etc., as

far as the point C. In drawing these lines move the pencil away from the body, that is, from A D to A B and from D C to B C.

Fig. 4 is an exercise in free-hand lettering. The finished exercise, with all guide lines erased, should have the appearance shown in *Fig. 4* of *PLATE I*. The guide lines are drawn as shown in *Fig. 37*. First draw the center line E F and light pencil lines Y Z and T X, $\frac{3}{8}$ inch from the border lines. Now, with the T-square, draw the line G, $\frac{1}{4}$ inch from the top line and the line H, $\frac{5}{32}$ inch below G. The word "*LETTERING*" is to be placed between these two lines. Draw the line I, $\frac{3}{16}$ inch below H. The lines I, J, etc., to K are all $\frac{5}{32}$ inch apart.

We now practice the lower-case letters. Draw the line L, $\frac{3}{16}$ inch below K and a light line $\frac{1}{8}$ inch above K to limit the height of the small letters. The space between L and M is $\frac{5}{32}$ inch. The lines M and N are drawn in the same manner as K and L. The space between N and O should be $\frac{1}{4}$ inch. The line P is drawn $\frac{5}{32}$ inch below O. Q is also $\frac{5}{32}$ inch below P. The lines Q and R are drawn $\frac{3}{16}$ inch apart as are M and N. The remainder of the lines S, U, V and W are drawn $\frac{5}{32}$ inch apart.

The center line is a great aid in centering the word "*LETTERING*," the alphabets, numerals, etc. The words "*THE*" and "*PROFICIENCY*" should be indented about $\frac{3}{8}$ inch as they are the first words of paragraphs. To draw the guide lines, mark off distances of $\frac{1}{4}$ inch on any line such as J and with the 60-degree triangle draw light pencil lines cutting the parallel lines. The letters should be sketched in pencil, the ordinary letters such as E, F, H, N, R, etc. being made of a width equal to about $\frac{3}{4}$ the height. Letters like A, M and W are wider. The space between the letters depends upon the draftsman's taste but the beginner should remember that letters next to an A or an L should be placed near them and that greater space should be left on each side of an I or between letters whose sides are parallel; for instance there should be more space between an N and E than between an E and H. On account of the space above the lower line of the L, a letter following an L should be close to it. If a T follows a T or the letter L follows an L they should be placed near together. In all lettering the letters should be placed so that the general effect is pleasing. After the four figures are

completed, the lettering for name, address and date should be pencilled. With the T-square draw a pencil line $\frac{5}{8}$ inch above the top border line at the right-hand end. This line should be about 3 inches long. At a distance of $\frac{5}{8}$ inch above this line draw another line of about the same length. These are the guide lines for the word *PLATE I*. The letters should be pencilled free hand and the student may use the 60-degree guide lines if he desires.

The guide lines of the date, name and address are similarly drawn in the lower margin. The date of completing the drawing should be placed under *Fig. 3* and the name and address at the right under *Fig. 4*. The street address is unnecessary. It is a good plan to draw lines $\frac{5}{8}$ inch apart on a separate sheet of paper and pencil the letters in order to know just how much space each word will require. The insertion of the words "*Fig. 1*," "*Fig. 2*," etc., is optional with the student. He may leave them out if he desires; but we would advise him to do this extra lettering for the practice and for convenience in reference. First draw with the T-square two parallel lines $\frac{5}{8}$ inch apart under each exercise; the lower line being $\frac{1}{8}$ inch above the horizontal center line or above the lower border line.

Inking. After all of the pencilling of *PLATE I* has been completed the exercises should be inked. The pen should first be examined to make sure that the nibs are clean, of the same length and come together evenly. To fill the pen with ink use an ordinary steel pen or the quill in the bottle, if Higgin's Ink is used. Dip the quill or pen into the bottle and then inside between the nibs of the line pen. The ink will readily flow from the quill into the space between the nibs as soon as it is brought in contact. Do not fill the pen too full, if the ink fills about $\frac{1}{4}$ the distance to the adjusting screw it usually will be sufficient. If the filling has been carefully done it will not be necessary to wipe the outsides of the blades. However, any ink on the outside should be wiped off with a soft cloth or a piece of chamois.

The pen should now be tried on a separate piece of paper in order that the width of the line may be adjusted. In the first work where no shading is done, a firm distinct line should be used. The beginner should avoid the extremes; a very light line makes

the drawing have a weak, indistinct appearance, and very heavy lines detract from the artistic appearance and make the drawing appear heavy.

In case the ink does not flow freely, wet the finger and touch it to the end of the pen. If it then fails to flow, draw a slip of thin paper between the nibs (thus removing the dried ink) or clean thoroughly and fill. Never lay the pen aside without cleaning.

In ruling with the line pen it should be held firmly in the right hand almost perpendicular to the paper. If grasped too firmly the width of the line may be varied and the draftsman soon becomes fatigued. The pen is usually held so that the adjusting screw is away from the T-square, triangles, etc. Many draftsmen incline the pen slightly in the direction in which it is moving.

To ink *Fig. 1*, place the T-square with the head at the working edge as in pencilling. First ink all of the horizontal lines moving the T-square from A to D. In drawing these lines considerable care is necessary; both nibs should touch the paper and the pressure should be uniform. Have sufficient ink in the pen to finish the line as it is difficult for a beginner to stop in the middle of the line and after refilling the pen make a smooth continuous line. While inking the lines A, E, F, G, H, I, etc., greater care should be taken in starting and stopping than while pencilling. Each line should start *exactly* in the pencil line A D and stop in the line B C. The lines A D and B C are inked, using the triangle and T-square.

Fig. 2 is inked in the same manner as it was pencilled; the lines being drawn, sliding the triangle along the T-square in the successive positions.

In inking *Fig. 3*, the same care is necessary as with the preceding, and after the oblique lines are inked the border lines are finished. In *Fig. 4* the border lines should be inked in first and then the border lines of the plate. The border lines should be quite heavy as they give the plate a better appearance. The intersections should be accurate, as any running over necessitates erasing.

The line pen may now be cleaned and laid aside. It can be

cleaned by drawing a strip of blotting paper between the nibs or by means of a piece of cloth or chamois. The lettering should be done free-hand using a steel pen. If the pen is very fine, accurate work may be done but the pen is likely to catch in the paper, especially if the paper is rough. A coarser pen will make broader lines but is on the whole preferable. Gillott's 404 is as fine a pen as should be used. After inking *Fig. 4*, the plate number, date and name should be inked, also free-hand. After inking the words "*Fig. 1*," "*Fig. 2*," etc., all pencil lines should be erased. In the finished drawing there should be no center lines, construction lines or letters other than those in the name, date, etc.

The sheet should be cut to a size of 11 inches by 15 inches, the dash line outside the border line of *PLATE I* indicating the edge.

PLATE II.

Penciling. The drawing paper used for *PLATE II* should be laid out as described with *PLATE I*, that is, the border lines, center line and rectangles for *Figs. 1* and *2*. To lay out *Figs. 3*, *4* and *5* proceed as follows: Draw a line with the T-square parallel to the horizontal center line and $\frac{3}{8}$ inch below it. Also draw another similar line $4\frac{5}{8}$ below the center line. The two lines will form the top and bottom of *Figs. 3*, *4* and *5*. Now measure off $2\frac{1}{4}$ inches on either side of the center on the horizontal center line and call the points Y and Z. On either side of Y and Z and at a distance of $\frac{1}{4}$ inch draw vertical parallel lines. Now draw a vertical line A D, $4\frac{1}{4}$ inches from the line Y and a vertical line B C $4\frac{1}{4}$ inches from the line Z. We now have three rectangles each 4 inches broad and $4\frac{1}{4}$ inches high. *Figs. 1* and *2* are pencilled in exactly the same way as was *Fig. 1* of *PLATE I*, that is, horizontal lines are drawn $\frac{1}{4}$ inch apart.

Fig. 3 is an exercise to show the use of a 60-degree triangle with a T-square. Lay off the distances A E, E F, F G, G H, etc. to B each $\frac{1}{4}$ inch. With the 60 degree triangle resting on the upper edge of the T-square, draw lines through these points, E, F, G, H, I, J, etc., forming an angle of 30 degrees with the horizontal. The last line drawn will be A L. In drawing these lines move the pencil from A B to B C. Now find the distance

between the lines on the vertical B L and mark off these distances on the line B C commencing at L. Continue the lines from A L to N C. Commencing at N mark off distances on A D equal to those on B C and finish drawing the oblique lines.

Fig. 4 is an exercise for intersection. Lay off distances of $\frac{1}{4}$ inch on A B and A D. With the T-square draw fine pencil lines through the points E, F, G, H, I, etc., and with the T-square and triangle draw vertical lines through the points L, M, N, O, P, etc. In drawing this figure draw every line exactly through the points indicated as the symmetrical appearance of the small squares can be attained only by accurate pencilling.

The oblique lines in *Fig. 5* form an angle of 60 degrees with the horizontal. As in *Figs. 3* and *4* mark off the line A B in divisions of $\frac{1}{4}$ inch and draw with the T-square and 60-degree triangle the oblique lines through these points of division moving the pencil from A B to B C. The last line thus drawn will be A L. Now mark off distances of $\frac{1}{4}$ inch on C D beginning at L. The lines may now be finished.

Inking. *Fig. 1* is designed to give the beginner practice in drawing lines of varying widths. The line E is first drawn. This line should be rather fine but should be clear and distinct. The line F should be a little wider than E; the greater width being obtained by turning the adjusting screw from one-quarter to one-half a turn. The lines G, H, I, etc., are drawn; each successive line having greater width. M and N should be the same and quite heavy. From N to D the lines should *decrease* in width. To complete the inking of *Fig. 1*, draw the border lines. These lines should have about the same width as those in *PLATE I*.

Fig. 2 is an exercise in drawing lines frequently used by draftsmen. The first four lines should be dotted, the dots and spaces being uniform. The next four lines are dash lines similar to those used for dimensions. These lines should be drawn with dashes about $\frac{3}{4}$ inch long and the lines should be fine, yet distinct.

The following four lines are called dot and dash lines. The dashes are about $\frac{3}{4}$ inch long and a dot between as shown. In the regular practice of drafting the length of the dashes depends upon the size of the drawing — $\frac{1}{2}$ inch to 1 inch being common. The last four lines are similar, two dots being used between the

dashes. After completing the dot and dash lines, draw the border lines of the rectangle as before.

In inking *Fig. 3*, the pencil lines are followed. Great care should be exercised in starting and stopping. The lines should begin in the border lines and the end should not run over.

The lines of *Fig. 4* must be drawn carefully, as there are so many intersections. The lines in this figure should be lighter than the border lines. If every line does not coincide with the points of division L, M, N, Q, P, etc., some will appear farther apart than others.

Fig. 5 is similar to *Fig. 3*, the only difference being in the angle which the oblique lines make with the horizontal.

After completing the five figures draw the border lines of the plate and then letter the plate number, date and name, and the figure numbers, as in *PLATE I*. The plate should then be cut to the proper size, 11 inches by 15 inches.

PLATE III.

Pencilling. The horizontal and vertical center lines and the border lines for *PLATE III* are laid out in the same manner as were those of *PLATE II*. To draw the squares for the six figures, proceed as follows:

Measure off two inches on either side of the vertical center line and draw light pencil lines through these points parallel to the vertical center line. These lines will form the sides A D and B C of *Figs. 2* and *5*. Parallel to these lines and at a distance of $\frac{1}{2}$ inch draw similar lines to form the sides B C of *Figs. 1* and *4* and A D of *Figs. 3* and *6*. The vertical sides A D of *Figs. 1* and *4* and B C of *Figs. 3* and *6* are formed by drawing lines perpendicular to the horizontal center line at a distance of $6\frac{1}{2}$ inches from the center.

The horizontal sides D C of *Figs. 1, 2* and *3* are drawn with the T-square $\frac{1}{2}$ inch above the horizontal center line. To draw the top lines of these figures, draw (with the T-square) a line $4\frac{1}{2}$ inches above the horizontal center line. The top lines of *Figs. 4, 5* and *6* are drawn $\frac{1}{2}$ inch below the horizontal center line. The squares are completed by drawing the lower lines D C, $4\frac{1}{2}$ inches below the horizontal center line. The figures of *PLATES I* and *II*

were constructed in rectangles; the exercises of *PLATE III* are, however, drawn in squares, having the sides 4 inches long.

In drawing *Fig. 1*, first divide *A D* and *A B* (or *D C*) into 4 equal parts. As these lines are four inches long, each length will be 1 inch. Now draw horizontal lines through *E*, *F* and *G* and vertical lines through *L*, *M* and *N*. These lines are shown dotted in *Fig. 1*. Connect *A* and *B* with the intersection of lines *E* and *M*, and *A* and *D* with the intersection of lines *F* and *L*. Similarly draw *D J*, *J C*, *I B* and *I C*. Also connect the points *P*, *O*, *I* and *J* forming a square. The four diamond shaped areas are formed by drawing lines from the middle points of *A D*, *A B*, *B C* and *D C* to the middle points of lines *A P*, *A O*, *O B*, *I B* etc., as shown in *Fig. 1*.

Fig. 2 is an exercise of straight lines. Divide *A D* and *A B* into four equal parts and draw horizontal and vertical lines as in *Fig. 1*. Now divide these dimensions, *A L*, *M N*, etc. and *E F*, *G B* etc. into four equal parts (each $\frac{1}{4}$ inch). Draw light pencil lines with the T-square and triangle as shown in *Fig. 2*.

In *Fig. 3*, divide *A B* and *A D* into eight parts, each length being $\frac{1}{2}$ inch. Through the points *H*, *I*, *J*, *K*, *L*, *M* and *N* draw vertical lines with the triangle. Through *O*, *P*, *Q*, *R*, *S*, *T* and *U* draw horizontal lines with the T-square. Now draw lines connecting *O* and *H*, *P* and *I*, *Q* and *J*, etc. These lines can be drawn with the 45-degree triangle, as they form an angle of 45 degrees with the horizontal. Starting at *N* draw lines from *A B* to *B C* at an angle of 45 degrees. Also draw lines from *A D* to *D C* through the points *O*, *P*, *Q*, *R*, etc., forming angles of 45 degrees with *D C*.

Fig. 4 is drawn with the compasses. First draw the diagonals *A C* and *D B*. With the T-square draw the line *E H*. Now mark off on *E H* distances of $\frac{1}{4}$ inch. With the compasses set so that the point of the lead is 2 inches from the needle point, describe the circle passing through *E*. With *H* as a center draw the arcs *F G* and *I J* having a radius of $1\frac{3}{4}$ inches. In drawing these arcs be careful not to go beyond the diagonals, but stop at the points *F* and *G* and *I* and *J*. Again with *H* as the center and a radius of $1\frac{1}{2}$ inches draw a circle. The arcs *K L* and *M N* are drawn in the same manner as were arcs *F G* and *I J*; the

radius being $1\frac{1}{4}$ inches. Now draw circles, with H as the center, of 1 , $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ inch radius, passing through the points P, T, etc.

Fig. 5 is an exercise with the line pen and compasses. First draw the diagonals A C and D B, the horizontal line L M and the vertical line E F passing through the center Q. Mark off distances of $\frac{1}{2}$ inch on L M and E F and draw the lines N N' O O' and N R, O S, etc., through these points, forming the squares N R R' N', O S S' O', etc. With the bow pencil adjusted so that the distance between the pencil point and the needle point is $\frac{1}{2}$ inch draw the arcs having centers at the corners of the squares. The arc whose center is N will be tangent to the lines A L and A E and the arc whose center is O will be tangent to N N' and N R. Since P T, T T', T' P' and P' P are each 1 inch long and form the square, the arcs drawn with Q as a center will form a circle.

To draw *Fig. 6*, first draw the center lines E F and L M. Now find the centers of the small squares A L I E, L B F I etc. Through the center I draw the construction lines H I T and R I P forming angles of 30 degrees with the horizontal. Now adjust the compasses to draw circles having a radius of one inch. With I as a center, draw the circle H P T R. With the same radius (one inch) draw the arcs with centers at A, B, C and D. Also draw the semi-circles with centers at L, F, M and E. Now draw the arcs as shown having centers at the centers of the small squares A L I E, L B F I, etc. To locate the centers of the six small circles within the circle H P T R, draw a circle with a radius of $\frac{1}{16}$ inch and having the center in I. The small circles have a radius of $\frac{5}{16}$ inch.

Inking. In inking this plate, the outlines of the squares of the various figures are inked only in *Figs. 2 and 3*. In *Fig. 1* the only lines to be inked are those shown in full lines in *PLATE III*. First ink the star and then the square and diamonds. The cross hatching should be done *without* measuring the distance between the lines and without the aid of any cross hatching device as this is an exercise for practice. The lines should be about $\frac{1}{16}$ inch apart. After inking erase all construction lines.

In inking *Fig. 2* be careful not to run over lines. Each line should coincide with the pencil line. The student should

first ink the horizontal lines L, M and N and the vertical lines E, F and G. The short lines should have the same width but the border lines, A B, B C, C D and D A should be a little heavier.

Fig. 3 is drawn entirely with the 45-degree triangle. In inking the oblique lines make P I, R K, T M, etc., a light distinct line. The alternate lines O H, Q J, S L, etc., should be somewhat heavier. All of the lines which slope in the opposite direction are light. After inking *Fig. 3* all horizontal and vertical lines (except the border lines) should be erased. The border lines should be slightly heavier than the light oblique lines.

The only instrument used in inking *Fig. 4* is the compasses. In doing this exercise adjust the legs of the compasses so that the pen will always be perpendicular to the paper. If this is not done both nibs will not touch the paper and the line will be ragged. In inking the arcs, see that the pen stops *exactly* at the diagonals. The circle passing through T and the small inner circle should be dotted as shown in *PLATE III*. After inking the circles and arcs erase the construction lines that are without the outer circles but leave in *pencil* the diagonals inside the circle.

In *Fig. 5* draw all arcs *first* and then draw the straight lines meeting these arcs. It is much easier to draw straight lines meeting arcs, or tangent to them, than to make the arcs tangent to straight lines. As this exercise is difficult, and in all mechanical and machine drawing arcs and tangents are frequently used, the beginner is advised to draw this exercise several times. Leave all construction lines in pencil.

Fig. 6, like *Fig. 4*, is an exercise with compasses. If *Fig. 6* has been laid out accurately in pencil, the inked arcs will be tangent to each other and the finished exercise will have a good appearance. If, however, the distances were not accurately measured and the lines carefully drawn the inked arcs will not be tangent. The arcs whose centers are L, F, M and E and A, B, C and D should be heavier than the rest. The small circles may be drawn with the bow pen. After inking the arcs all construction lines should be erased.

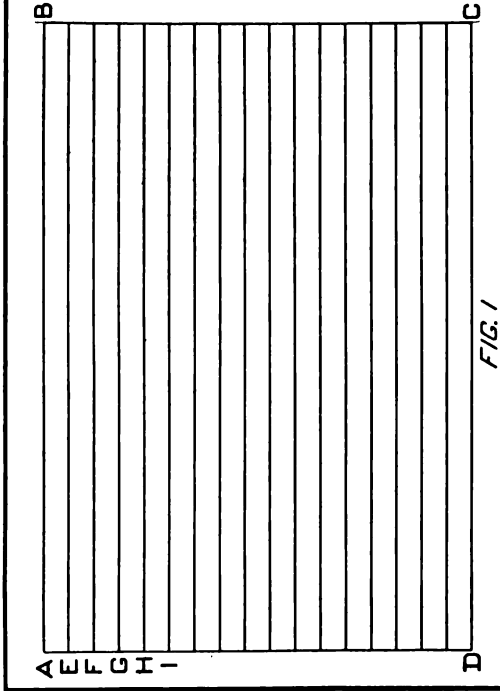


FIG. 1

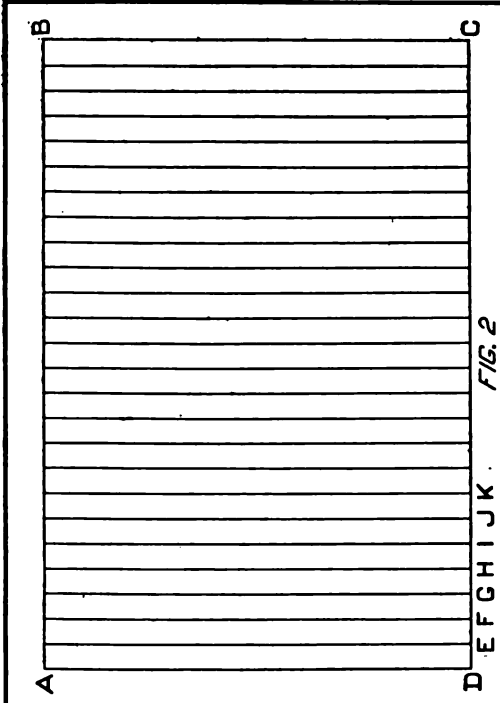


FIG. 2

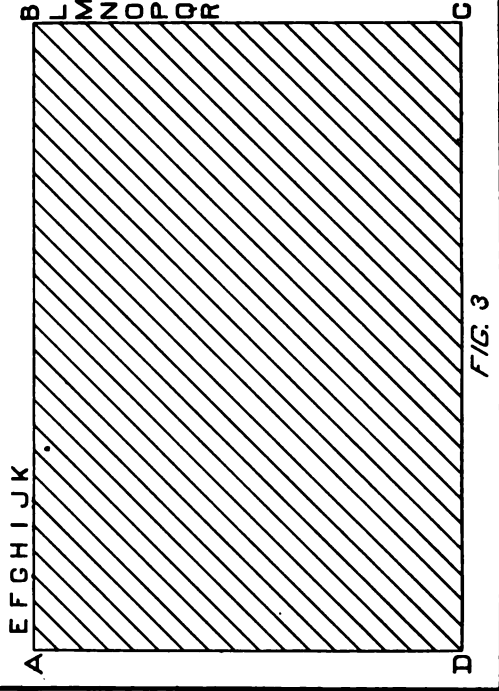


FIG. 3

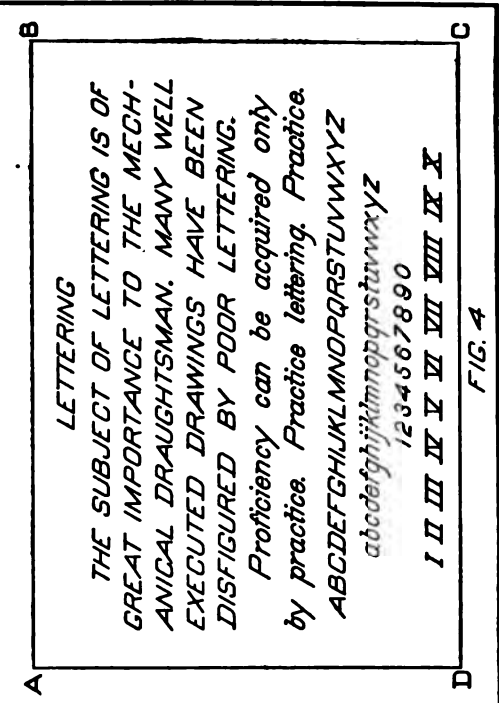


FIG. 4

LETTERING

THE SUBJECT OF LETTERING IS OF GREAT IMPORTANCE TO THE MECHANICAL DRAUGHTSMAN. MANY WELL EXECUTED DRAWINGS HAVE BEEN DISFIGURED BY POOR LETTERING.

Proficiency can be acquired only by practice. Practice lettering. Practice.

ABCDEFGHIJKLMNOPQRSTUVWXYZ

abcdefghijklmnopqrstuvwxyz

1234567890

I II III IV V VI VII VIII IX X

PLATE II

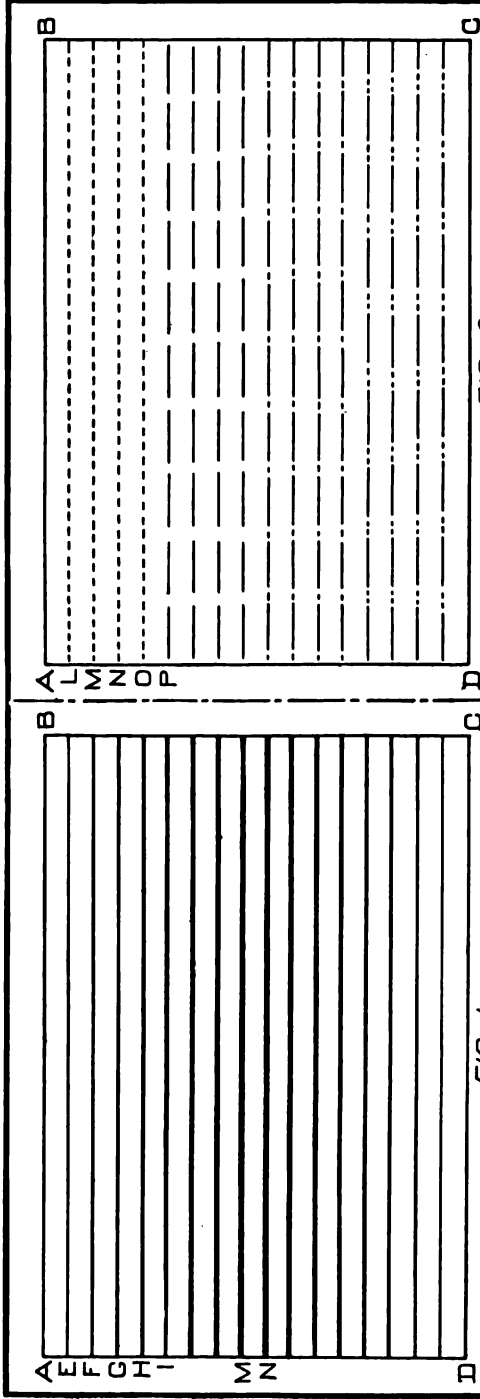


FIG. 1

Y

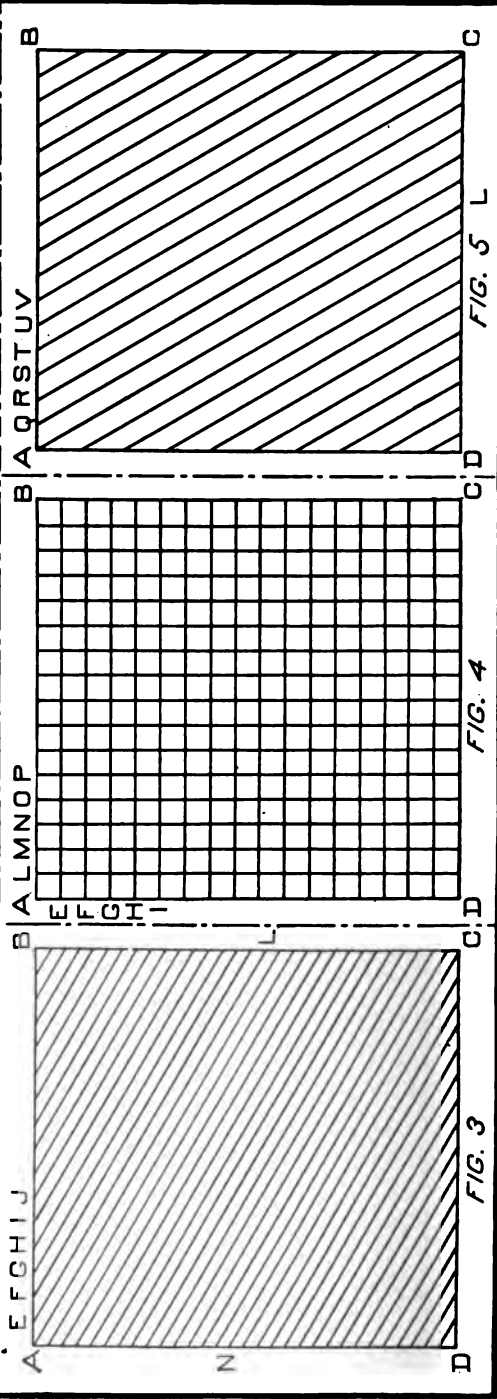


FIG. 2

Z

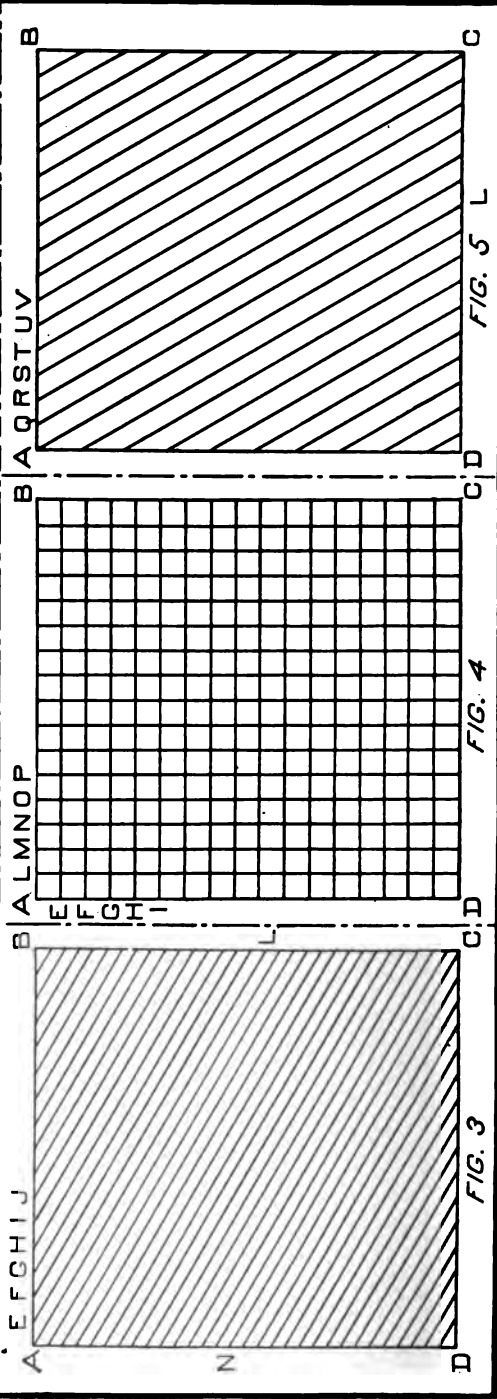


FIG. 3

Y

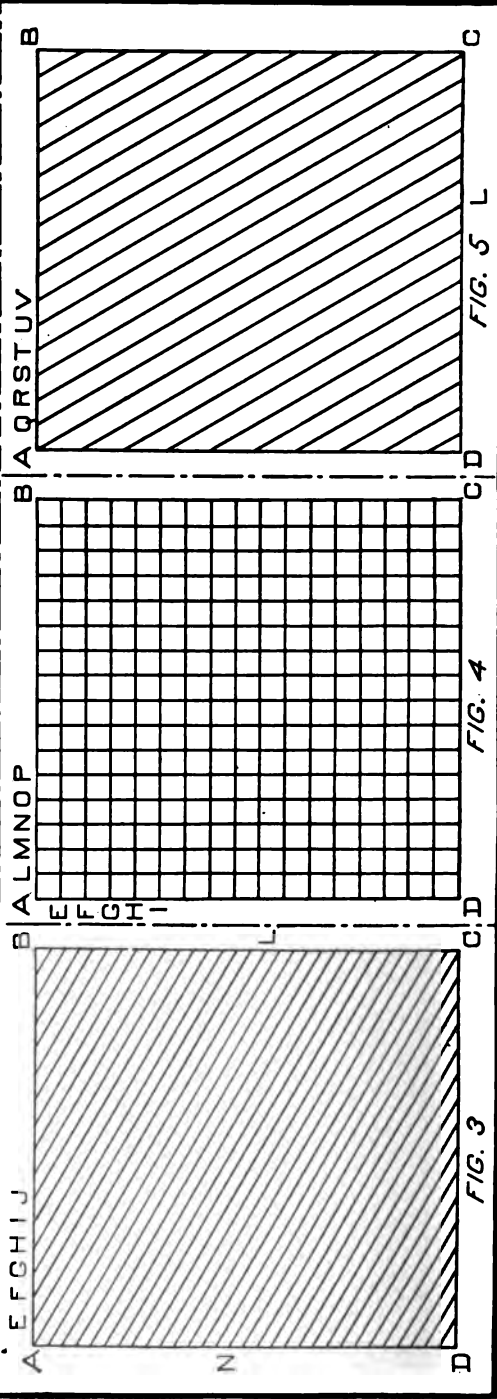


FIG. 4

Z

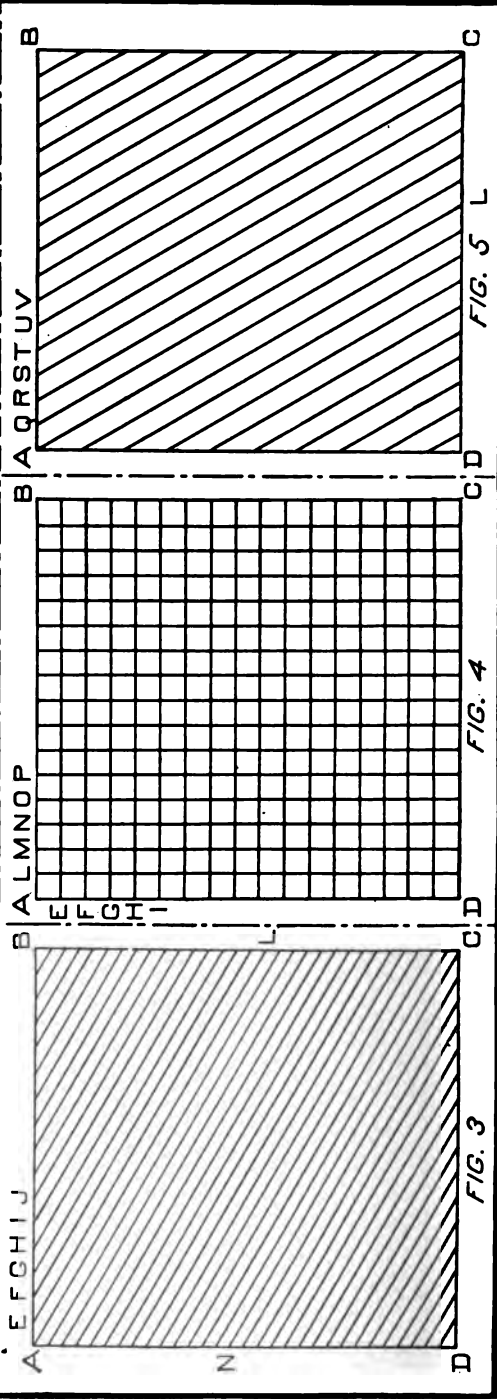


FIG. 5

Z

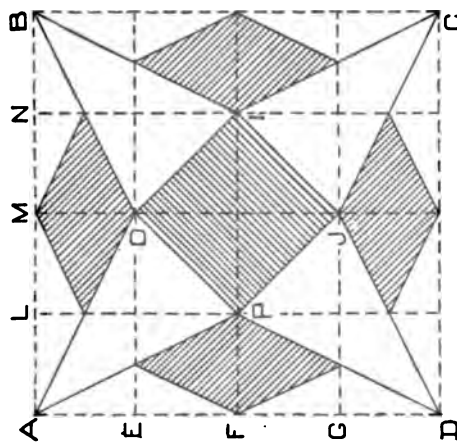


FIG. 1

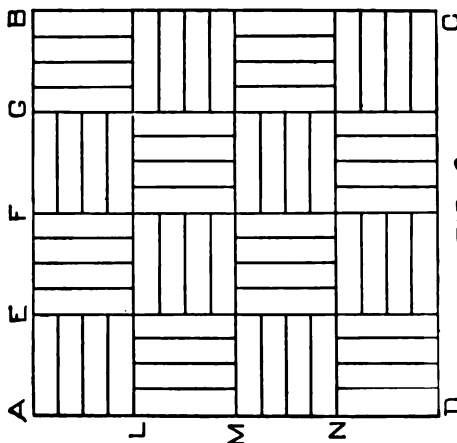


FIG. 2

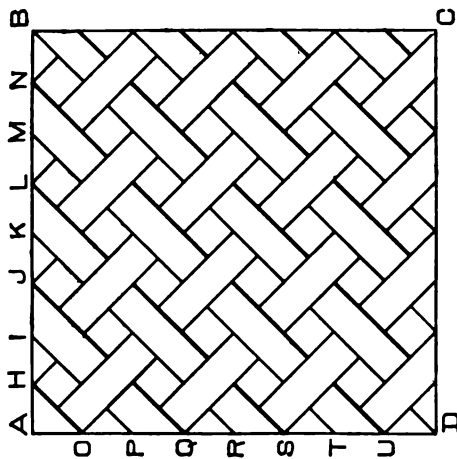


FIG. 3

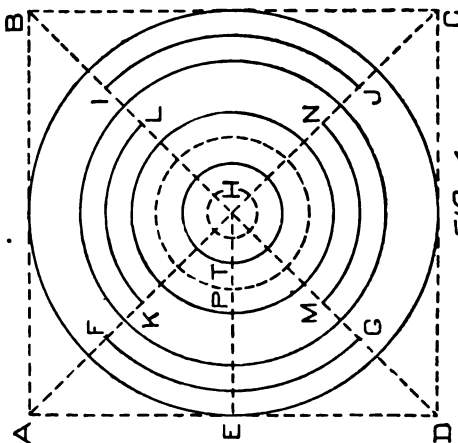


FIG. 4

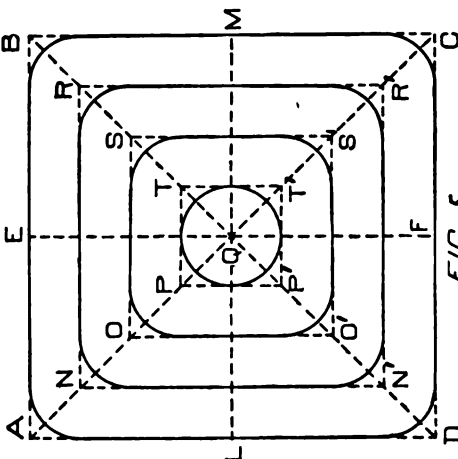


FIG. 5

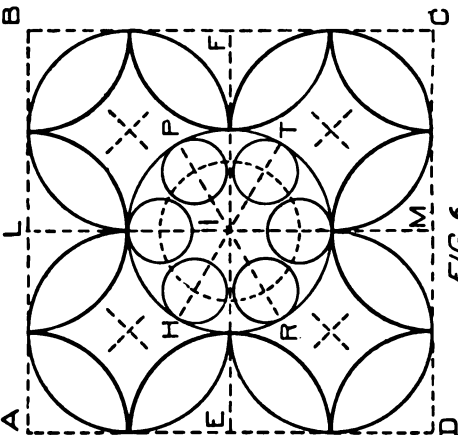


FIG. 6

SECTION 2.

MECHANICAL DRAWING.

PART II.

GEOMETRICAL DEFINITIONS.

A **point** is used for marking position ; it has neither length, breadth nor thickness.

A **line** has length only ; it is produced by the motion of a point.

A *straight line* or *right line* is one that has the same direction throughout. It is the shortest distance between any two of its points.

A *curved line* is one that is constantly changing in direction. It is sometimes called a curve.

A *broken line* is one made up of several straight lines.

Parallel lines are equally distant from each other at all points.

A *horizontal line* is one having the direction of a line drawn upon the surface of water that is at rest. It is a line parallel to the horizon.

A *vertical line* is one that lies in the direction of a thread suspended from its upper end and having a weight at the lower end. It is a line that is perpendicular to a horizontal plane.

Lines are *perpendicular* to each other, if when they cross, the four angles formed are equal. If they meet and form two equal angles they are perpendicular.

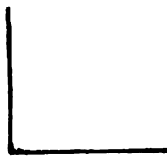
An *oblique line* is one that is neither vertical nor horizontal.

In Mechanical Drawing, lines drawn along the edge of the T square, when the head of the T square is resting against the left-hand edge of the board, are called horizontal lines. Those drawn at right angles or perpendicular to the edge of the T square are called vertical.

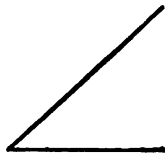
If two lines cut each other, they are called *intersecting lines*, and the point at which they cross is called the *point of intersection*.

ANGLES.

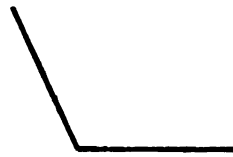
An **angle** is formed when two straight lines meet. An angle is often defined as being the difference in direction of two straight lines. The lines are called the *sides* and the point of meeting is called the *vertex*. The size of an angle depends upon the amount of divergence of the sides and is independent of the length of these lines.



RIGHT ANGLE.



ACUTE ANGLE.



OBTUSE ANGLE.

If one straight line meet another and the angles thus formed are equal they are **right angles**. When two lines are perpendicular to each other the angles formed are right angles.

An **acute angle** is less than a right angle.

An **obtuse angle** is greater than a right angle.

SURFACES.

A **surface** is produced by the motion of a line; it has two dimensions, — length and breadth.

A **plane figure** is a plane bounded on all sides by lines; the space included within these lines (if they are straight lines) is called a *polygon* or a *rectilinear figure*.

TRIANGLES.

A **triangle** is a figure enclosed by three straight lines. It is a polygon of three sides. The bounding lines are the *sides*, and the points of intersection of the sides are the *vertices*. The *angles* of a triangle are the angles formed by the sides.

A **right-angled triangle**, often called a *right triangle*, is one that has a right angle.

An **acute-angled triangle** is one that has all of its angles acute.

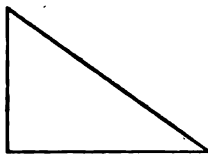
An **obtuse-angled triangle** is one that has an obtuse angle.

In an **equilateral triangle** all of the sides are equal.

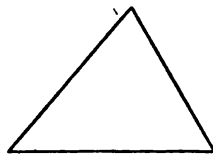
If all of the *angles* of a triangle are equal, the figure is called an **equiangular** triangle.

A triangle is called **scalene**, when no two of its sides are equal.

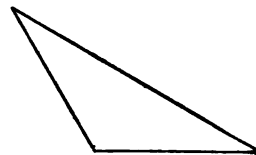
In an **isosceles** triangle two of the sides are equal.



RIGHT ANGLED TRIANGLE.



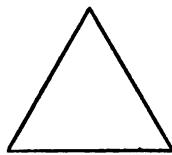
ACUTE ANGLED TRIANGLE.



OBTUSE ANGLED TRIANGLE.

The *base* of a triangle is the lowest side ; however, any side may be taken as the base. In an isosceles triangle the side which is not one of the equal sides is usually considered the base.

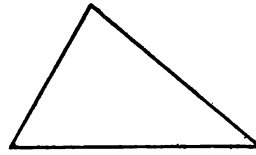
The *altitude* of a triangle is the perpendicular drawn from the vertex to the base.



EQUILATERAL TRIANGLE.



ISOSCELES TRIANGLE.



SCALENE TRIANGLE.

QUADRILATERALS.

A **quadrilateral** is a plane figure bounded by four straight lines.

The *diagonal* of a quadrilateral is a straight line joining two opposite vertices.



QUADRILATERAL.



TRAPEZOID.



PARALLELOGRAM.

A **trapezium** is a quadrilateral, no two of whose sides are parallel.

A **trapezoid** is a quadrilateral having two sides parallel.

The *bases* of a trapezoid are its parallel sides. The *altitude* is the perpendicular distance between the bases.

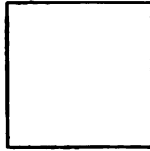
A **parallelogram** is a quadrilateral whose opposite sides are parallel.

The *altitude* of a parallelogram is the perpendicular distance between the bases which are the parallel sides.

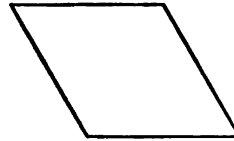
There are four kinds of parallelograms:



RECTANGLE.



SQUARE.



RHOMBUS.

A **rectangle** is a parallelogram, all of whose angles are right angles. The opposite sides are equal.

A **square** is a rectangle, all of whose sides are equal.

A **rhombus** is a parallelogram which has four equal sides; but the angles are not right angles.

A **rhomboid** is a parallelogram whose adjacent sides are unequal; the angles are not right angles.

POLYGONS.

A **polygon** is a plane figure bounded by straight lines.

The boundary lines are called the *sides* and the sum of the sides is called the *perimeter*.

Polygons are classified according to the number of sides.

A **triangle** is a polygon of *three* sides.

A **quadrilateral** is a polygon of *four* sides.

A **pentagon** is a polygon of *five* sides.

A **hexagon** is a polygon of *six* sides.

A **heptagon** is a polygon of *seven* sides.

An **octagon** is a polygon of *eight* sides.

A **decagon** is a polygon of *ten* sides.

A **dodecagon** is a polygon of *twelve* sides.

An **equilateral** polygon is one all of whose sides are equal.

An **equiangular** polygon is one all of whose angles are equal.

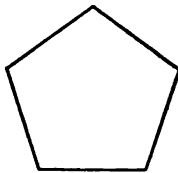
A **regular polygon** is one all of whose angles are equal and all of whose sides are equal.

CIRCLES.

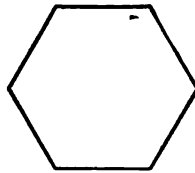
A **circle** is a plane figure bounded by a curved line, every point of which is equally distant from a point within called the center.

The curve which bounds the circle is called the **circumference**. Any portion of the circumference is called an *arc*.

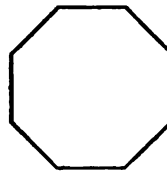
The **diameter** of a circle is a straight line drawn through the center and terminating in the circumference. A **radius** is a straight line joining the center with the circumference. It has a length equal to one half the diameter. All radii (plural of radius) are equal and all diameters are equal since a diameter equals two radii.



PENTAGON.



HEXAGON.

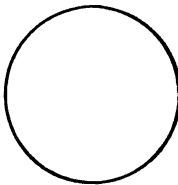


OCTAGON.

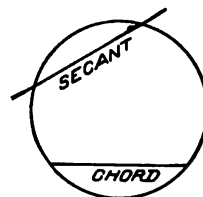
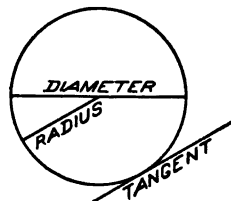
An arc equal to one-half the circumference is called a *semi-circumference*, and an arc equal to one-quarter of the circumference is called a *quadrant*. A quadrant may mean the sector, arc or angle.

A **chord** is a straight line joining the extremities of an arc. It is a line drawn across a circle that does not pass through the center.

A **secant** is a straight line which intersects the circumference in two points.



CIRCLE.

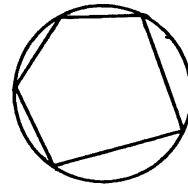
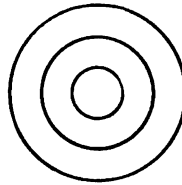
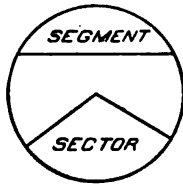


A **tangent** is a straight line which touches the circumference at only one point. It does not intersect the circumference. The point at which the tangent touches the circumference is called the *point of tangency* or *point of contact*.

A **sector** of a circle is the portion or area included between an arc and two radii drawn to the extremities of the arc.

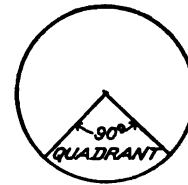
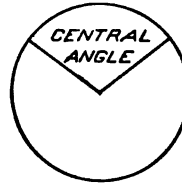
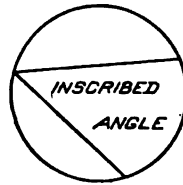
A **segment** of a circle is the area included between an arc and its chord.

Circles are **tangent** when the circumferences touch at only one point and are **concentric** when they have the same center.



An **inscribed angle** is an angle whose vertex lies in the circumference and whose sides are chords. It is measured by one-half the intercepted arc.

A **central angle** is an angle whose vertex is at the center of the circle and whose sides are radii.



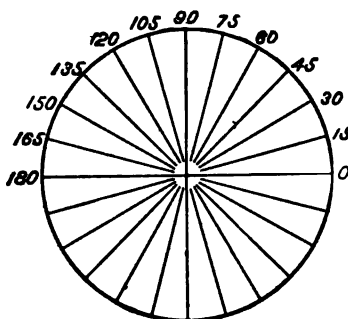
An **inscribed polygon** is one whose vertices lie in the circumference and whose sides are chords.

MEASUREMENT OF ANGLES.

To measure an angle describe an arc with the center at the vertex of the angle and having any convenient radius. The portion of the arc included between the sides of the angle is the measure of the angle. If the arc has a constant radius the greater the divergence of the sides, the longer will be the arc. If there are several arcs drawn with the same center, the intercepted arcs will have different lengths but they will all be the *same fraction* of the entire circumference.

In order that the size of an angle or arc may be stated with-

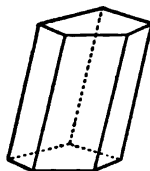
out saying that it is a certain fraction of a circumference, the circumference is divided into 360 equal parts called degrees. Thus we can say that an angle contains 45 degrees, which means that it is $\frac{45}{360} = \frac{1}{8}$ of a circumference. In order to obtain accurate measurements each degree is divided into 60 equal parts called *minutes* and each minute is divided into 60 equal parts called *seconds*. Angles and arcs are usually measured by means of an instrument called a protractor which has already been explained.



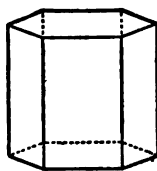
SOLIDS.

A **polyedron** is a solid bounded by planes. The bounding planes are called the *faces* and their intersections *edges*. The intersections of the edges are called *vertices*.

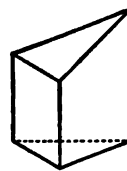
A polygon having four faces is called a **tetraedron**; one having six faces a **hexaedron**; of eight faces an **octaedron**; of twelve faces a **dodecaedron**, etc.



PRISM.



RIGHT PRISM.



TRUNCATED PRISM.

A **prism** is a polyedron, of which two opposite faces, called *bases*, are equal and parallel; the other faces, called *lateral faces* are parallelograms.

The area of the lateral faces is called the *lateral area*.

The *altitude* of a prism is the perpendicular distance between the bases.

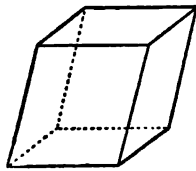
Prisms are *triangular*, *quadrangular*, etc., according to the shape of the base.

A **right prism** is one whose lateral edges are perpendicular to the bases.

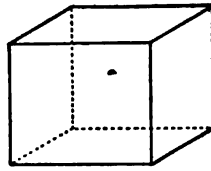
A **regular prism** is a right prism having regular polygons for bases.

A **parallelopiped** is a prism whose bases are parallelograms. If the edges are all perpendicular to the bases it is called a **right parallelopiped**.

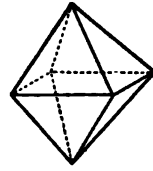
A **rectangular parallelopiped** is a right parallelopiped whose bases are rectangles ; all the faces are rectangles.



PARALLELOPIPED.



RECTANGULAR PARALLELOPIPED.



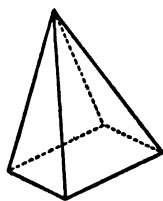
OCTAHEDRON.

A **cube** is a rectangular parallelopiped all of whose faces are squares.

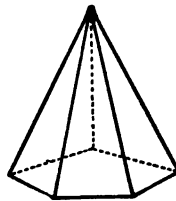
A **truncated prism** is the portion of a prism included between the base and a plane not parallel to the base.

PYRAMIDS.

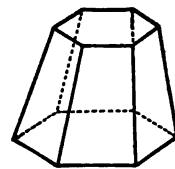
A **pyramid** is a polyedron one face of which is a polygon (called the base) and the other faces are triangles having a common vertex.



PYRAMID.



REGULAR PYRAMID.



FRUSTUM OF PYRAMID.

The vertices of the triangles form the *vertex* of the pyramid. The *altitude* of the pyramid is the perpendicular distance from the vertex to the base.

A pyramid is called **triangular, quadrangular, etc.**, according to the shape of the base.

A **regular pyramid** is one whose base is a regular polygon

and whose vertex lies in the perpendicular erected at the center of the base.

A **truncated pyramid** is the portion of a pyramid included between the base and a plane not parallel to the base.

A **frustum** of a pyramid is a truncated pyramid whose bases are parallel.

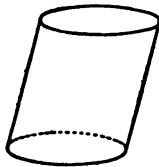
The *altitude* of a frustum of a pyramid is the perpendicular distance between the bases.

CYLINDERS.

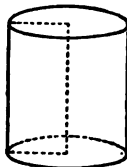
A **cylindrical surface** is a curved surface generated by the motion of a straight line which touches a curve and continues parallel to itself.

A **cylinder** is a solid bounded by a cylindrical surface and two parallel planes intersecting this surface.

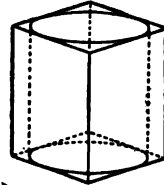
The parallel faces are called *bases*.



CYLINDER.



RIGHT CYLINDER.



INSCRIBED CYLINDER.

The *altitude* of a cylinder is the perpendicular distance between the bases.

A **circular cylinder** is a cylinder whose base is a circle.

A **right cylinder** or a *cylinder of revolution* is a cylinder generated by the revolution of a rectangle about one side as an axis.

A prism whose base is a regular polygon may be inscribed in or circumscribed about a circular cylinder.

The cylindrical area is called the *lateral area*. The *total area* is the area of the bases added to the lateral area.

CONES.

A **conical surface** is a curved surface generated by the motion of a straight line, one point of which is fixed and the end or ends of which move in a curve.

A **cone** is a solid bounded by a conical surface and a plane which cuts the conical surface.

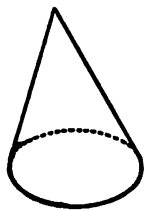
The plane is called the *base* and the curved surface the lateral area.

The *vertex* is the fixed point.

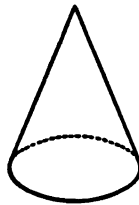
The *altitude* of a cone is the perpendicular distance from the vertex to the base.

An *element* of a cone is a straight line from the vertex to the perimeter of the base.

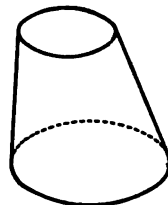
A **circular cone** is a cone whose base is a circle.



CONE.



RIGHT CIRCULAR CONE.



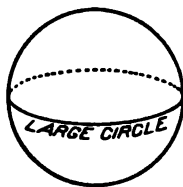
FRUSTUM OF CONE.

A **right circular cone** or **cone of revolution** is a cone whose axis is perpendicular to the base. It may be generated by the revolution of a right triangle about one of the perpendicular sides as an axis.

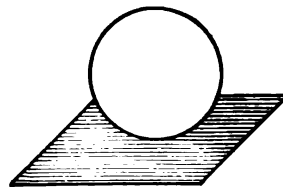
A **frustum** of a cone is the solid included between the base and a plane parallel to the base.



SPHERE.



SPHERE.



TANGENT PLANE.

The *altitude* of a frustum of a cone is the perpendicular distance between the bases.

SPHERES.

A **sphere** is a solid bounded by a curved surface, every point of which is equally distant from a point within called the center.

The *radius* of a sphere is a straight line drawn from the

center to the surface. The *diameter* is a straight line drawn through the center and having its extremities in the surface.

A sphere may be generated by the revolution of a semi-circle about its diameter as an axis.

An *inscribed polyedron* is a polyedron whose vertices lie in the surface of the sphere.

An *circumscribed polyedron* is a polyedron whose faces are tangent to a sphere.

A *great circle* is the intersection of the spherical surface and a plane passing through the center of a sphere.

A *small circle* is the intersection of the spherical surface and a plane which does not pass through the center.

A sphere is *tangent* to a plane when the plane touches the surface in only one point. A plane perpendicular to the extremity of a radius is tangent to the sphere.

CONIC SECTIONS.

If a plane intersects a cone the geometrical figures thus formed are called conic sections. A plane perpendicular to the base and passing through the vertex of a right circular cone forms an isosceles triangle. If the plane is parallel to the base the intersection of the plane and conical surface will be the circumference of a circle.

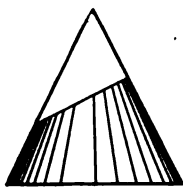


Fig. 1.



Fig. 2.



Fig. 3.



Fig. 4.

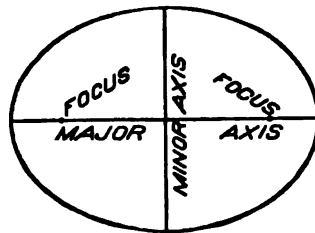
Ellipse. The ellipse is a curve formed by the intersection of a plane and a cone, the plane being oblique to the axis but not cutting the base. If a plane is passed through a cone as shown in Fig. 1 or through a cylinder as shown in Fig 2, the curve of intersection will be an ellipse. An ellipse may be defined as being *a curve generated by a point moving in a plane, the sum of the distances of the point to two fixed points being always constant.*

The two fixed points are called the **foci** and lie on the

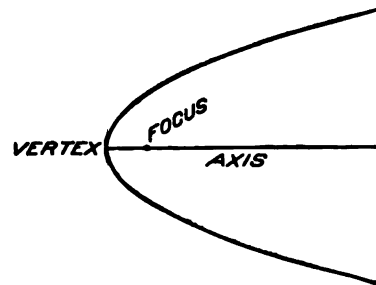
longest line that can be drawn in the ellipse. One of these points is called a *focus*.

The longest line that can be drawn in an ellipse is called the **major axis** and the shortest line, passing through the center, is called the **minor axis**. The minor axis is perpendicular to the middle point of the major axis and the point of intersection is called the center.

An ellipse may be constructed if the major and minor axes are given or if the foci and one axis are known.



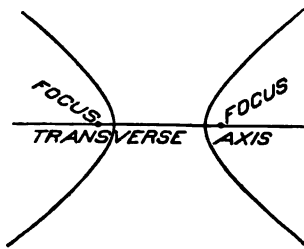
ELLIPSE.



PARABOLA.

Parabola. The parabola is a curve formed by the intersection of a cone and a plane parallel to an element as shown in Fig. 3. The curve is not a closed curve. The branches approach parallelism.

A parabola may be defined as being a curve every point of which is equally distant from a line and a point.



HYPERBOLA.

The point is called the **focus** and the given line the **directrix**. The line perpendicular to the directrix and passing through the focus is the **axis**. The intersection of the axis and the curve is the **vertex**.

Hyperbola. This curve is formed by the intersection of a plane and a cone, the plane being parallel to the axis of the cone as shown in Fig. 4. Like the parabola, the curve is not a closed curve; the branches constantly diverge.

An hyperbola is defined as being a plane curve such that the difference of the distances from any point in the curve to two fixed points is equal to a given distance.

The two fixed points are the **foci** and the line passing through them is the **transverse axis**.

Rectangular Hyperbola. The form of hyperbola most used in Mechanical Engineering is called the rectangular hyperbola because it is drawn with reference to rectangular co-ordinates. This curve is constructed as follows: In Fig. 5, O X and O Y are the two co-ordinates drawn at right angles to each other. These lines are also called axes or asymptotes. Assume A to be a known point on the curve. In drawing this curve for the theoretical indicator card, this point A is the point of cut-off.

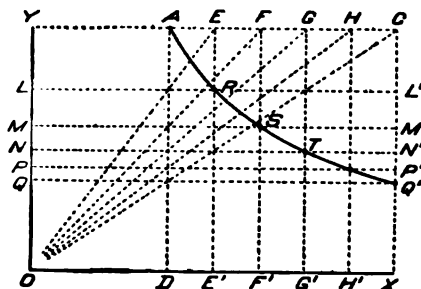


Fig. 5.

Draw AC parallel to OX and AD perpendicular to OX. Now mark off any convenient points on AC such as E, F, G, and H; and through these points draw EE', FF', GG', and HH' perpendicular to OX. Connect E, F, G, H and C with O. Through the points of intersection of the oblique lines and the vertical line AD draw the horizontal lines LL', MM', NN', PP' and QQ'. The first point on the curve is the assumed point A, the second point is R, the intersection of LL' and EE'. The third is the intersection S of MM' and FF'; the fourth is the intersection T of NN' and GG'. The other points are found in the same way.

In this curve the products of the co-ordinates of all points are equal. Thus $LR \times RE' = MS \times SF' = NT \times TG'$.

ODONTOIDAL CURVES.

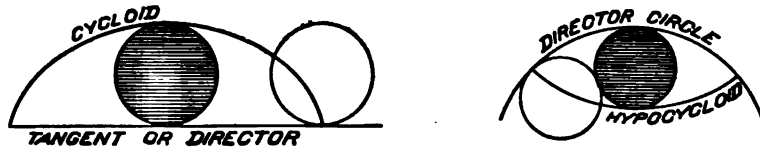
The outlines of the teeth of gears must be drawn accurately because the smoothness of running depends upon the shape of the teeth. The two classes of curves generally employed in drawing gear teeth are the cycloidal and involute.

Cycloid. The cycloid is a curve generated by a point on the circumference of a circle which rolls on a straight line tangent to the circle.

The rolling circle is called the *describing* or *generating circle*

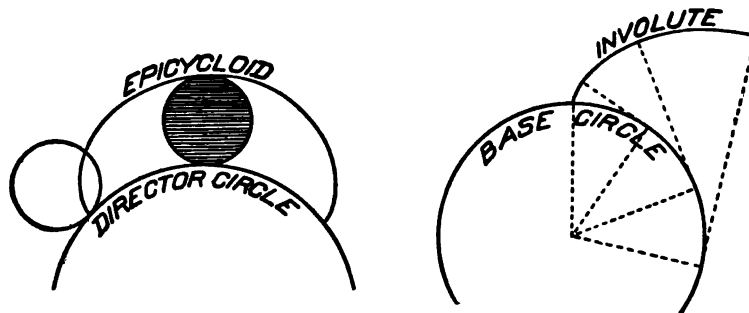
and the point, the *describing* or *generating point*. The tangent along which the circle rolls is called the *director*.

In order that the curve may be a true cycloid the circle must roll without any slipping.



Epicycloid. If the generating circle rolls upon the *outside* of an arc or circle, called the *director circle*, the curve thus generated is called an epicycloid. The method of drawing this curve is the same as that for the cycloid.

Hypocycloid. In case the generating circle rolls upon the *inside* of an arc or circle, the curve thus generated is called the hypocycloid. The circle upon which the generating circle rolls is



called the *director circle*. If the generating circle has a diameter equal to the radius of the director circle the hypocycloid becomes a straight line.

Involute. If a thread or fine wire is wound around a cylinder or circle and then unwound, the end will describe a curve called an involute. The involute may be defined as being *a curve generated by a point in a tangent rolling on a circle known as the base circle*.

The construction of the ellipse, parabola, hyperbola and odontoid curves will be taken up in detail with the plates.

PLATE IV.

Pencilling. The horizontal and vertical center lines and the border lines for *PLATE IV* should be laid out in the same manner as were those for *PLATE I*. There are to be six figures on this plate and to facilitate the laying out of the work, the following lines should be drawn: measure off $2\frac{1}{4}$ inches on both sides of the vertical center line and through these points draw vertical lines as shown in dot and dash lines on *PLATE IV*. In these six spaces the six figures are to be drawn, the student placing them in the centers of the spaces so that they will present a good appearance. In locating the figures, they should be placed a little above the center so that there will be sufficient space below to number the problem.

The figures of the problems should first be drawn lightly in pencil and after the entire plate is completed the lines should be inked. In pencilling, all intersections must be formed with great care as the accuracy of the results depends upon the pencilling. Keep the pencil points in good order at all times and draw lines *exactly* through intersections.

GEOMETRICAL PROBLEMS.

The following problems are of great importance to the mechanical draughtsman. The student should solve them with care; he should not do them blindly, but should understand them so that he can apply the principles in later work.

PROBLEM I. To Bisect a Given Straight Line.

Draw the horizontal straight line *A C* about 3 inches long. With the extremity *A* as a center and any convenient radius (about 2 inches) describe arcs above and below the line *A C*. With the other extremity *C* as a center and with the same radius draw short arcs above and below *A C* intersecting the first arcs at *D* and *E*. The radius of these arcs must be greater than one-half the length of the line in order that they may intersect. Now draw the straight line *D E* passing through the intersections *D* and *E*. This line cuts the line *A C* at *F* which is the middle point.

$$A F = F C$$

Proof. Since the points D and E are equally distant from A and C a straight line drawn through them is perpendicular to A C at its middle point F.

PROBLEM 2. To Construct an Angle Equal to a Given Angle.

Draw the line O C about 2 inches long and the line O A of about the same length. The angle formed by these lines may be any convenient size (about 45 degrees is suitable). This angle A O C is the given angle.

Now draw F G a horizontal line about $2\frac{1}{4}$ inches long and let F the left-hand extremity be the vertex of the angle to be constructed.

With O as a center and any convenient radius (about $1\frac{1}{2}$ inches) describe the arc L M cutting both O A and O C. With F as a center and the same radius draw the indefinite arc O Q. Now set the compass so that the distance between the pencil and the needle point is equal to the chord L M. With Q as a center and a radius equal to L M draw an arc cutting the arc O Q at P. Through F and P draw the straight line F E. The angle E F G is the required angle since it is equal to A O C.

Proof. Since the chords of the arcs L M and P Q are equal the arcs are equal. The angles are equal because with equal radii equal arcs are intercepted by equal angles.

PROBLEM 3. To Draw Through a Given Point a Line Parallel to a Given Line.

First Method. Draw the horizontal straight line A C about $3\frac{1}{2}$ inches long and assume the point P about $1\frac{1}{2}$ inches above A C. Through the point P draw an oblique line F E forming any convenient angle with A C. (Make the angle about 60 degrees). Now construct an angle equal to P F C having the vertex at P and one side the line E P. (See problem 2). This may be done as follows: With F as a center and any convenient radius, describe the arc L M. With the same radius draw the indefinite arc N O using P as the center. With N as a center and a radius equal to the chord L M, draw an arc cutting the arc N O at O. Through the points P and O draw a straight line which will be parallel to A C.

Proof. If two straight lines are cut by a third making the corresponding angles equal, the lines are parallel.

PROBLEM 4. To Draw Through a Given Point a Line Parallel to a Given Line.

Second Method. Draw the straight line A C about $3\frac{1}{4}$ inches long and assume the point P about $1\frac{1}{2}$ inches above A C. With P as a center and any convenient radius (about $2\frac{1}{2}$ inches) draw the indefinite arc E D cutting the line A C. Now with the same radius and with D as a center, draw an arc P Q. Set the compass so that the distance between the needle point and the pencil is equal to the chord P Q. With D as a center and a radius equal to P Q, describe an arc cutting the arc E D at H. A line drawn through P and H will be parallel to A C.

Proof. Draw the line Q H. Since the arcs P Q and H D are equal and have the same radii, the angles P H Q and H Q D are equal. Two lines are parallel if the alternate interior angles are equal.

PROBLEM 5. To Draw a Perpendicular to a Line from a Point in the Line.

First Method. When the point is near the middle of the line.

Draw the horizontal line A C about $3\frac{1}{2}$ inches long and assume the point P near the middle of the line. With P as a center and any convenient radius (about $1\frac{1}{4}$ inches) draw two arcs cutting the line A C at E and F. Now with E and F as centers and any convenient radius (about $2\frac{1}{2}$ inches) describe arcs intersecting at O. The line O P will be perpendicular to A C at P.

Proof. The points P and O are equally distant from E and F. Hence a line drawn through them is perpendicular to the middle point of E F which is P.

PROBLEM 6. To Draw a Perpendicular to a Line from a Point in the Line.

Second Method. When the point is near the end of the line.

Draw the line A C about $3\frac{1}{2}$ inches long. Assume the given point P to be about $\frac{3}{4}$ inch from the end A. With any point D as a center and a radius equal to D P, describe an arc, cutting A C at E. Through E and D draw the diameter E O. A line from O to P is perpendicular to A C at P.

Proof. The angle O P E is inscribed in a semi-circle ; hence it is a right angle, and the sides O P and P E are perpendicular to each other.

After completing these figures draw pencil lines for the lettering. The words "*PLATE IV*" and the date and name should be placed in the border, as in preceding plates. To letter the words "Problem 1," "Problem 2," etc., draw horizontal lines $\frac{1}{4}$ inch above the horizontal center line and the lower border line. Draw another line $\frac{3}{16}$ inch above, to limit the height of the P, b and l. Draw a third line $\frac{1}{8}$ inch above the lower line as a guide line for the tops of the small letters.

Inking. In inking *PLATE IV* the figures should be inked first. The line A C of Problem 1 should be a full line as it is the given line ; the arcs and line D E, being construction lines should be dotted. In Problem 2, the sides of the angles should be full lines. Make the chord L M and the arcs dotted, since as before, they are construction lines.

In Problem 3, the line A C is the given line and P O is the line drawn parallel to it. As E F and the arcs do not form a part of the problem but are merely construction lines, drawn as an aid in locating P O, they should be dotted. In Problems 4, 5 and 6, the assumed lines and those found by means of the construction lines should be full lines. The arcs and construction lines should be dotted. In Problem 6, the entire circumference need not be inked, only that part is necessary that is used in the problem. The inked arc should however be of sufficient length to pass through the points O, P and E.

After inking the figures, the border lines should be inked with a heavy line as before. Also, the words "*PLATE IV*" and the date and the student's name. Under each problem the words "Problem 1," "Problem 2," etc., should be inked ; lower case letters being used as shown.

PLATE V.

Pencilling. In laying out the border lines and centre lines follow the directions given for *PLATE IV*. The dot and dash lines should be drawn in the same manner as there are to be six problems on this plate.

PROBLEM 7. To Draw a Perpendicular to a Line from a Point without the Line.

Draw the horizontal straight line A C about $3\frac{1}{4}$ inches long. Assume the point P about $1\frac{1}{2}$ inches above the line. With P as a center and any convenient radius (about 2 inches) describe an arc cutting A C at E and F. The radius of this arc must always be such that it will cut A C in two points; the nearer the points E and F are to A and C, the greater will be the accuracy of the work. Now with E and F as centers and any convenient radius (about $2\frac{1}{4}$ inches) draw the arcs intersecting below A C at T. A line through the points P and T will be perpendicular to A C.

In case there is not room below A C to draw the arcs, they may be drawn intersecting above the line as shown at N. Whenever convenient, draw the arcs below A C for greater accuracy.

Proof. Since P and T are equally distant from E and F, the line P T is perpendicular to A C.

PROBLEM 8. To Bisect a Given Angle.

First Method. When the sides intersect.

Draw the lines O C and O A forming any angle (from 45 to 60 degrees). These lines should be about 3 inches long. With O as a center and any convenient radius (about 2 inches) draw an arc intersecting the sides of the angle at E and F. With E and F as centers and a radius of $1\frac{1}{2}$ or $1\frac{3}{4}$ inches, describe short arcs intersecting at I. A line O D, drawn through the points O and I, bisects the angle.

In solving this problem the arc E F should not be too near the vertex if accuracy is desired.

Proof. The central angles A O D and D O C are equal because the arc E F is bisected by the line O D. The point I is equally distant from E and F.

PROBLEM 9. To Bisect a Given Angle.

Second Method. When the lines do not intersect.

Draw the lines A C and E F about 4 inches long and in the positions as shown on *PLATE V*. Draw A' C' and E' F' parallel to A C and E F and at such distance (about 1 inch) from them that they will intersect at O. Now bisect the angle C' O F' by

the method of Problem 8. Draw the arc G H and with G and H as centers draw the arcs intersecting at R. The line O R bisects the angle.

Proof. Since A' C' is parallel to A C and E' F' parallel to E F, the angle C' O F' is equal to the angle formed by the lines A C and E F. Hence as O R bisects angle C' O F' it also bisects the angle formed by the lines A C and E F.

PROBLEM 10. To Divide a Given Line into any Number of Equal Parts.

Let A C, about $3\frac{3}{4}$ inches long, be the given line. Let us divide it into 7 equal parts. Draw the line A J at least 4 inches long, forming any convenient angle with A C. On A J lay off, by means of the dividers or scale, points D, E, F, G, etc., each $\frac{1}{2}$ inch apart. If dividers are used the spaces need not be exactly $\frac{1}{2}$ inch. Draw the line J C and through the points D, E, F, G, etc., draw lines parallel to J C. These parallels will divide the line A C into 7 equal parts.

Proof. If a series of parallel lines, cutting two straight lines, intercept equal distances on one of these lines, they also intercept equal distances on the other.

PROBLEM 11. To Construct a Triangle having given the Three Sides.

Draw the three sides as follows:

A C, $2\frac{3}{4}$ inches long.

E F, $1\frac{1}{8}$ inches long.

M N, $2\frac{3}{8}$ inches long.

Draw R S equal in length to A C. With R as a center and a radius equal to E F describe an arc. With S as a center and a radius equal to M N draw an arc cutting the arc previously drawn, at T. Connect T with R and S to form the triangle.

PROBLEM 12. To Construct a Triangle having given One Side and the Two Adjacent Angles.

Draw the line M N $3\frac{1}{4}$ inches long and draw two angles A O D and E F G. Make the angle A O D about 30 degrees and E F G about 60 degrees.

Draw R S equal in length to M N and at R construct an

angle equal to $\angle AOD$. At S construct an angle equal to $\angle EFG$ by the method used in Problem 2. *PLATE V* shows the necessary arcs. Produce the sides of the angles thus constructed until they meet at T . The triangle RTS will be the required triangle.

After drawing these six figures in pencil, draw the pencil lines for the lettering. The lines for the words "*PLATE V*," date and name, should be pencilled as explained on page 20. The words "Problem 7," "Problem 8," etc., are lettered as for *PLATE IV*.

Inking. In inking *PLATE V*, the same principles should be followed as stated with *PLATE IV*. The student should apply these principles and not make certain lines dotted just because they are shown dotted in *PLATE V*.

After inking the figures, the border lines should be inked and the lettering inked as already explained in connection with previous plates.

PLATE VI.

Pencilling. Lay out this plate in the same manner as the two preceding plates.

PROBLEM 13. To describe an Arc or Circumference through Three Given Points not in the same straight line.

Locate the three points A , B and C . Let the distance between A and B be about 2 inches and the distance between A and C be about $2\frac{1}{4}$ inches. Connect A and B and A and C . Erect perpendiculars to the middle points of AB and AC . This may be done as explained with Problem 1. With A and B as centers and a radius of about $1\frac{1}{2}$ inches, describe the arcs intersecting at I and J . With A and C as centers and with a radius of about $1\frac{3}{4}$ inches draw the arcs, intersecting at E and F . Now draw light pencil lines connecting the intersections I and J and E and F . These lines will intersect at O .

With O as a center and a radius equal to the distance OA , describe the circumference passing through A , B and C .

Proof. The point O is equally distant from A , B and C , since it lies in the perpendiculars to the middle points of AB and

A C. Hence the circumference will pass through A, B and C.

PROBLEM 14. To inscribe a Circle in a given Triangle.

Draw the triangle L M N of any convenient size. M N may be made $3\frac{1}{4}$ inches, L M, $2\frac{3}{4}$ inches, and L N, $3\frac{1}{2}$ inches. Bisect the angles M L N and L M N. The bisectors M I and L J may be drawn by the method used in Problem 8. Describe the arcs A C and E F, having centers at L and M respectively. The arcs intersecting at I and J are drawn as already explained. The bisectors of the angles intersect at O, which is the center of the inscribed circle. The radius of the circle is equal to the perpendicular distance from O to one of the sides.

Proof. The point of intersection of the bisectors of the angles of a triangle is equally distant from the sides.

PROBLEM 15. To inscribe a Regular Pentagon in a given Circle.

With O as a center and a radius of about $1\frac{1}{2}$ inches, describe the given circle. With the T square and triangles draw the center lines A C and E F. These lines should be perpendicular to each other and pass through O. Bisect one of the radii, such as O C, and with this point H as a center and a radius H E, describe the arc E P. This arc cuts the diameter A C at P. With E as a center and a radius E P, draw arcs cutting the circumference at L and Q. With the same radius and a center at L, draw the arc, cutting the circumference at M. To find the point N, use either M or Q as a center and the distance E P as a radius.

The pentagon is completed by drawing the chords E L, L M, M N, N Q and Q E.

PROBLEM 16. To inscribe a Regular Hexagon in a given Circle.

With O as a center and a radius of $1\frac{3}{8}$ inches draw the given circle. With the T square draw the diameter A D. With D as a center, and a radius equal to O D, describe arcs cutting the circumference at C and E. Now with C and E as centers and the same radius, draw the arcs, cutting the circumference at B and F. Draw the hexagon by joining the points thus formed.

To inscribe a regular hexagon in a circle mark off chords equal in length to the radius.

To inscribe an equilateral triangle in a circle the same method may be used. The triangle is formed by joining the opposite vertices of the hexagon.

Proof. The triangle OCD is an equilateral triangle by construction. Then the angle COD is one-third of two right angles and one-sixth of four right angles. Hence arc CD is one-sixth of the circumference and the chord is a side of a regular hexagon.

PROBLEM 17. To draw a line Tangent to a Circle at a given point on the circumference.

With O as a center and a radius of about $1\frac{1}{4}$ inches draw the given circle. Assume some point P on the circumference. Join the point P with the center O and through P draw a line FP perpendicular to PO . This may be done in any one of several methods. Since P is the extremity of OP the method given in Problem 6 of *PLATE IV*, may be used.

Produce PO to Q . With any center C , and a radius CP draw an arc or circumference passing through P . Draw EF a diameter of the circle whose center is C and through F and P draw the tangent.

Proof. A line perpendicular to a radius at its extremity is tangent to the circle.

PROBLEM 18. To draw a line Tangent to a Circle from a point outside the circle.

With O as a center and a radius of about 1 inch draw the given circle. Assume P some point outside of the circle about $2\frac{1}{2}$ inches from the center of the circle. Draw a straight line passing through P and O . Bisect PO and with the middle point F as a center describe the circle passing through P and O . Draw a line through P and the intersection of the two circumferences C . The line PC is tangent to the given circle. Similarly PE is tangent to the circle.

Proof. The angle PCO is inscribed in a semi-circle and hence is a right angle. Since PCO is a right angle PC is perpendicular to CO . The perpendicular to a radius at its extremity is tangent to the circumference.

Inking. In inking *PLATE VI* the same method should be

followed as in previous plates. The name and address should be lettered in inclined Gothic capitals as before.

PLATE VII.

Pencilling. *PLATE VII* should be laid out in the same manner as previous plates. Six problems on the ellipse, spiral, parabola and hyperbola are to be constructed in the six spaces.

PROBLEM 19. To draw an Ellipse when the Axes are given.

Draw the lines *L M* and *C D* about $3\frac{1}{4}$ and $2\frac{1}{4}$ inches long respectively. Let *C D* be perpendicular to *M N* at its middle point *P*. Make *C P* = *P D*. These two lines are the axes. With *C* as a center and a radius equal to one-half the major axis or equal to *L P*, draw the arc, cutting the major axis at *E* and *F*. These two points are the foci. Now mark off any convenient distances on *P M*, such as *A*, *B* and *G*.

With *E* as a center and a radius equal to *L A*, draw arcs above and below *L M*. With *F* as a center, and a radius equal to *A M* describe short arcs cutting those already drawn as shown at *N*. With *E* as a center and a radius equal to *L B* draw arcs above and below *L M* as before. With *F* as a center and a radius equal to *B M*, draw arcs intersecting those already drawn as shown at *O*. The point *P* and others are found by repeating the process. The student is advised to find at least 12 points on the curve — 6 above and 6 below *L M*. These 12 points with *L*, *C*, *M* and *D* will enable the student to draw the curve.

After locating these points, a free hand curve passing through them should be sketched.

PROBLEM 20. To draw an Ellipse when the two Axes are given.

Second Method. Draw the two axes *A B* and *P Q* in the same manner as for Problem 19. With *O* as a center and a radius equal to one-half the major axis, describe the circumference *A C D E F B*. Similarly with the same center and a radius equal to one-half the minor axis, describe a circle. Draw any radii such as *O C*, *O D*, *O E*, *O F*, etc., cutting both circumferences. These radii may be drawn with the 60 and 45 degree triangles. At the

points of intersection of the radii with the large circle C D E and F, draw *vertical* lines and from the intersection of the radii with the small circle C', D', E', and F', draw *horizontal* lines intersecting the vertical lines. The intersections of these lines are points on the curve.

As in Problem 19, a free hand curve should be sketched passing through these points. About five points in each quadrant will be sufficient.

PROBLEM 21. To draw an Ellipse by means of a Trammel.

As in the two preceding problems, draw the major and minor axes, U V and X Y. Take a slip of paper having a straight edge and mark off C B equal to one-half the major axis, and D B equal to the minor axis. Place the slip of paper in various positions keeping the point D on the major axis and the point C on the minor axis. If this is done the point B will mark various points on the curve. Find as many points as necessary and sketch the curve.

PROBLEM 22. To draw a Spiral of one turn in a circle.

Draw a circle with the center at O and a radius of $1\frac{1}{2}$ inches. Mark off on the radius O A, distances of one-eighth inch. As O A is $1\frac{1}{2}$ inches long there will be 12 of these distances. Draw circles through these points. Now draw radii O B, O C, O D, etc. each 30 degrees apart (use the 30 degree triangle). This will divide the circle into 12 equal parts. The curve starts at the center O. The next point is the intersection of the line O B and the first circle. The third point is the intersection of O C and the second circle. The fourth point is the intersection of O D and the third circle. Other points are found in the same way. Sketch in pencil the curve passing through these points.

PROBLEM 23. To draw a Parabola when the Abscissa and Ordinate are given.

Draw the straight line A B about three inches long. This line is the axis or as it is sometimes called the abscissa. At A and B draw lines perpendicular to A B. Also with the T square draw E C and F D, $1\frac{1}{2}$ inches above and below A B. Let A be

the vertex of the parabola. Divide A E into any number of equal parts and divide E C into the same number of equal parts. Through the points of division, R, S, T, U and V, draw horizontal lines and connect L, M, N, O and P, with A. The intersections of the horizontal lines with the oblique lines are points on the curve. For instance, the intersection of A L and the line V is one point and the intersection of A M and the line U is another.

The lower part of the curve A D is drawn in the same manner.

PROBLEM 24. To draw a Hyperbola when the abscissa E X, the ordinate A E and the diameter X Y are given.

Draw E F about 3 inches long and mark the point X, 1 inch from E and the point Y, 1 inch from X. With the triangle and T square, draw the rectangles A B D C and O P Q R such that A B is 1 inch in length and A C, 3 inches in length. Divide A E into any number of equal parts and A B into the same number of equal parts. Draw L X, M X and N X; also connect T, U and V with Y. The first point on the curve is the intersection A; the next is the intersection of T Y and L X; the third the intersection of U Y and M X. The remaining points are found in the same manner. The curve X C and the right-hand curve P Y Q are found by repeating the process.

Inking. In inking the figures on this plate, use the French or irregular curve and make full lines for the curves and their axes. The construction lines should be dotted. Ink in all the construction lines used in finding one-half of a curve, and in Problems 19, 20, 23 and 24 leave all construction lines in *pencil* except those inked. In Problems 21 and 22 erase all construction lines not inked. The trammel used in Problem 21 may be drawn in the position as shown, or it may be drawn outside of the ellipse in any convenient place.

The same lettering should be done on this plate as on previous plates.

PLATE VIII.

Pencilling. In laying out Plate VIII, draw the border lines and horizontal and vertical center lines as in previous plates, to divide the plate into four spaces for the four problems.

PROBLEM 25. To construct a Cycloid when the diameter of the generating circle is given.

With O' as a center and a radius of $\frac{1}{8}$ inch draw a circle, and tangent to it draw the indefinite horizontal straight line $A B$. Divide the circle into any number of equal parts (12 for instance) and through these points of division C, D, E, F , etc., draw horizontal lines. Now with the dividers set so that the distance between the points is equal to the chord of the arc $C D$, mark off the points L, M, N, O, P on the line $A B$, commencing at the point H . At these points erect perpendiculars to the center line $G O'$. This center line is drawn through the point O' with the T square and is the line of centers of the generating circle as it rolls along the line $A B$. Now with the intersections Q, R, S, T , etc., of these verticals with the center line as centers describe arcs of circles as shown. The points on the curve are the intersections of these arcs and the horizontal lines drawn through the points C, D, E, F , etc. Thus the intersection of the arc whose center is Q and the horizontal line through C is a point I on the curve. Similarly, the intersection of the arc whose center is R and the horizontal line through D is another point J on the curve. The remaining points, as well as those on the right-hand side, are found in the same manner. To obtain great accuracy in this curve, the circle should be divided into a large number of equal parts, because the greater the number of divisions the less the error due to the difference in length of a chord and its arc.

PROBLEM 26. To construct an Epicycloid when the diameter of the generating circle and the diameter of the director circle are given.

The epicycloid and hypocycloid may be drawn in the same manner as the cycloid if arcs of circles are used in place of the horizontal lines. With O as a center and a radius of $\frac{3}{4}$ inch describe a circle. Draw the diameter $E F$ of this circle and produce $E F$ to G such that the line $F G$ is $2\frac{3}{4}$ inches long. With G as a center and a radius of $2\frac{3}{4}$ inches describe the arc $A B$ of the director circle. With the same center G , draw the arc $P Q$ which will be the path of the center of the generating circle as it rolls along the arc $A B$. Now divide the generating circle into

any number of equal parts (twelve for instance) and through the points of division H, I, L, M, and N, draw arcs having G as a center. With the dividers set so that the distance between the points is equal to the chord H I, mark off distances on the director circle A F B. Through these points of division R, S, T, U, etc., draw radii intersecting the arc P Q in the points R', S', T', etc., and with these points as centers describe arcs of circles as in Problem 25. The intersections of these arcs with the arcs already drawn through the points H, I, L, M, etc., are points on the curve. Thus the intersection of the circle whose center is R' with the arc drawn through the point H is a point upon the curve. Also the arc whose center is S' with the arc drawn through the point I is another point on the curve. The remaining points are found by repeating this process.

PROBLEM 27. To draw an Hypocycloid when the diameter of the generating circle and the radius of the director circle are given.

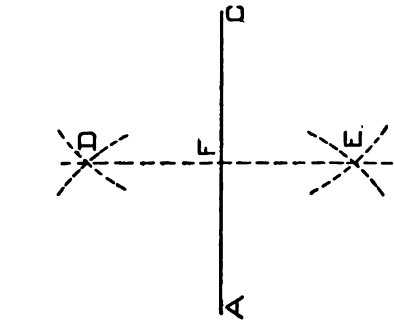
With O as a center and a radius of 4 inches describe the arc E F, which is the arc of the director circle. Now with the same center and a radius of $3\frac{1}{4}$ inches, describe the arc A B, which is the line of centers of the generating circle as it rolls on the director circle. With O' as a center and a radius of $\frac{3}{4}$ inch describe the generating circle. As before, divide the generating circle into any number of equal parts (12 for instance) and with these points of division L, M, N, O, etc., draw arcs having O as a center. Upon the arc E F, lay off distances Q R, R S, S T, etc., equal to the chord Q L. Draw radii from the points R, S, T, etc., to the center of the director circle O and describe arcs of circles having a radius equal to the radius of the generating circle, using the points G, I, J, etc., as centers. As in Problem 26, the intersections of the arcs are the points on the curve. By repeating this process, the right-hand portion of the curve may be drawn.

PROBLEM 28. To draw the Involute of a circle when the diameter of the base circle is known.

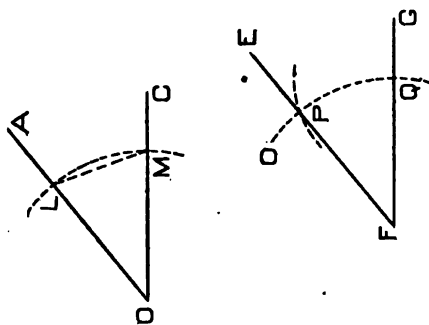
With point O as a center and a radius of 1 inch, describe the base circle. Now divide the circle into any number of equal parts (16 for instance) and connect the points of division with the cen-

ter of the circle by drawing the radii $O C$, $O D$, $O E$, $O F$, etc., to $O B$. At the point D , draw a light pencil line perpendicular to the radius $O D$. This line will be tangent to the circle. Similarly at the points E , F , G , H , etc., draw tangents to the circle. Now set the dividers so that the distance between the points will be equal to the chord of the arc $C D$, and measure this distance from D along the tangent. Beginning with the point E , measure on the tangent a distance equal to two of these chords, from the point F measure on the tangent three divisions, and from the point G measure a distance equal to four divisions on the tangent $G P$. Similarly, measure distances on the remaining tangents, each time adding the length of the chord. This will give the points Q , R , S and T . Now sketch a light pencil line through the points L , M , N , P , etc., to T . This curve will be the involute of the circle.

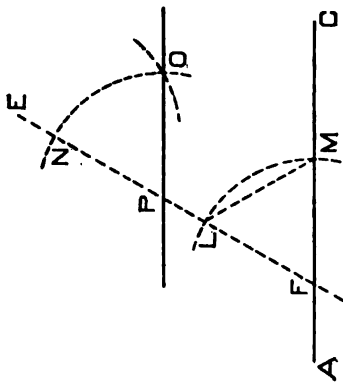
Inking. The same rules are to be observed in inking *PLATE VIII* as were followed in the previous plates, that is, the curves should be inked in a full line, using the French or irregular curve. All arcs and lines used in locating the points on one-half of the curve should be inked in dotted lines. The arcs and lines used in locating the points of the other half of the curve may be left in pencil in Problems 25 and 26. In Problem 28, all construction lines should be inked. After completing the problems the same lettering should be done on this plate as on previous plates.



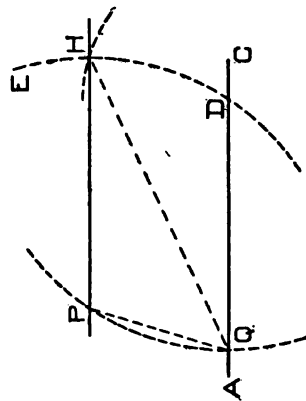
Problem 1



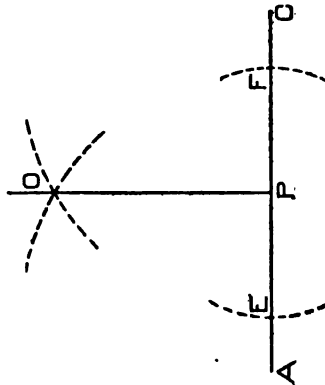
Problem 2



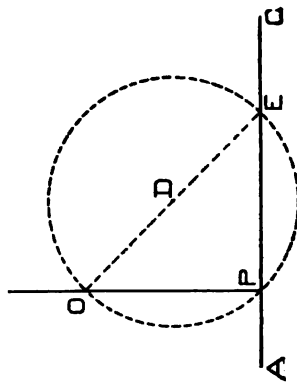
Problem 3



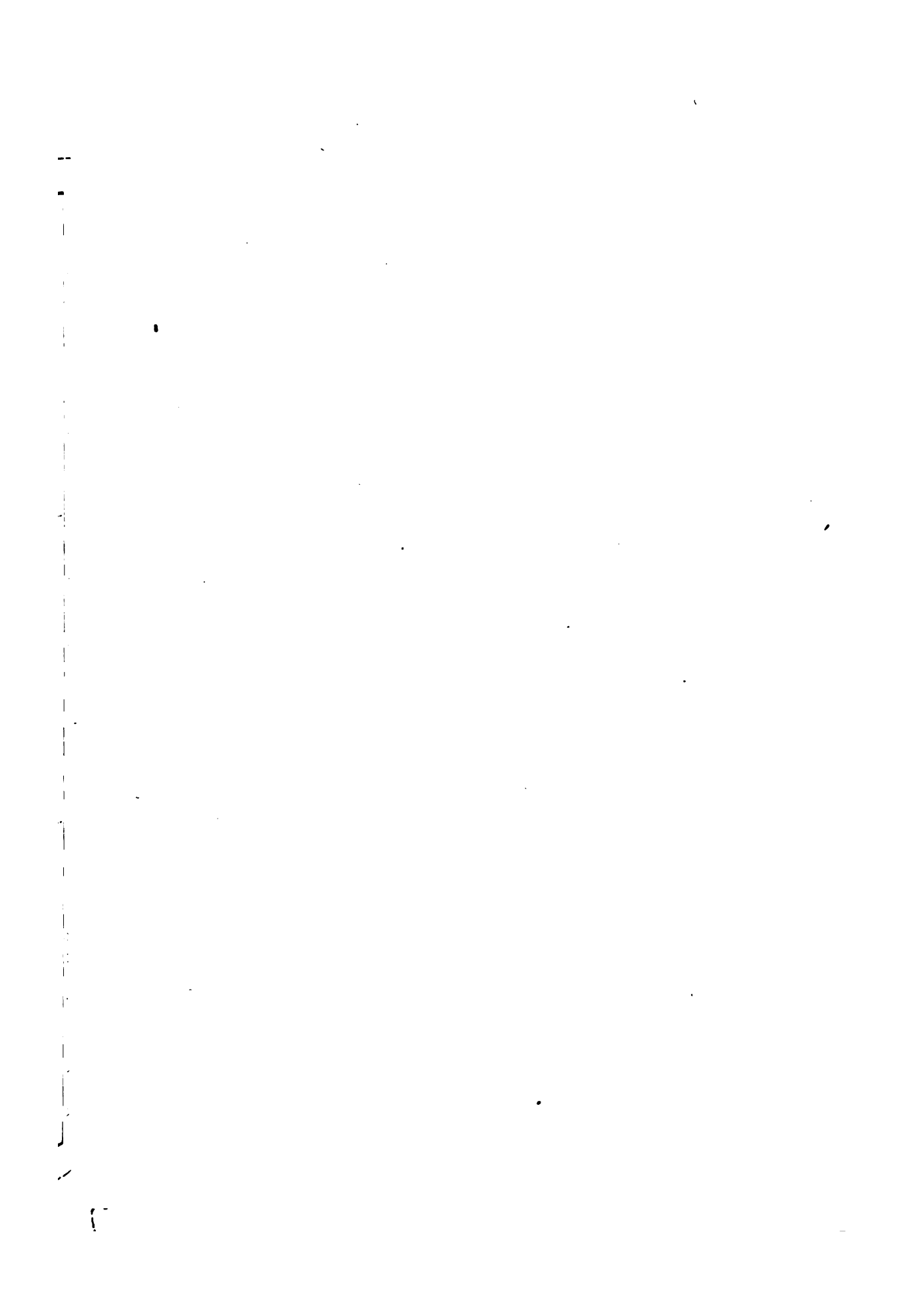
Problem 4

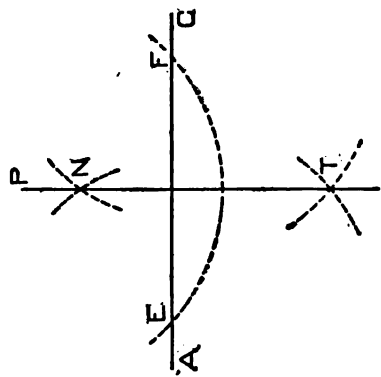


Problem 5

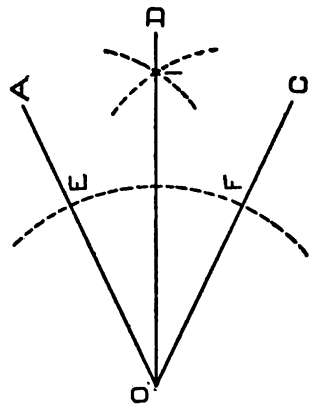


Problem 6

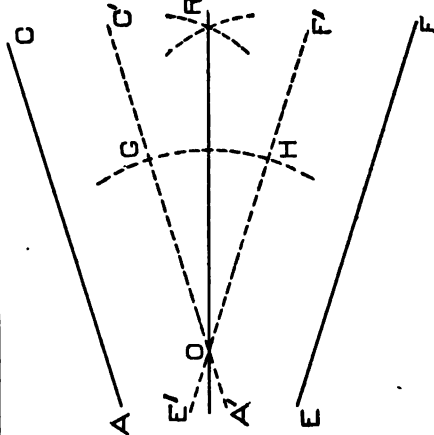




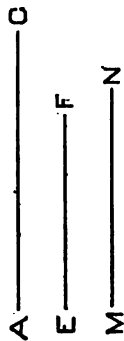
Problem 7



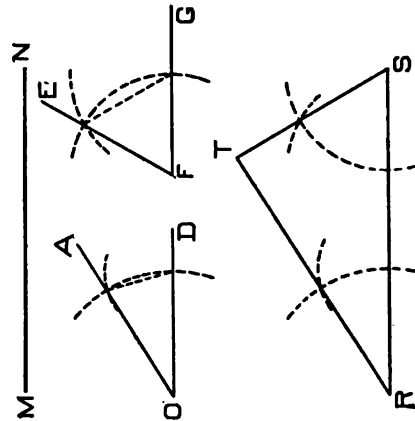
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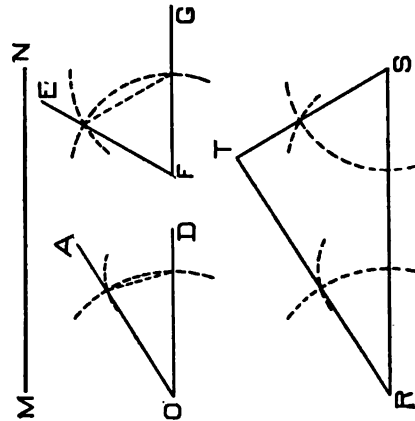
Problem 9



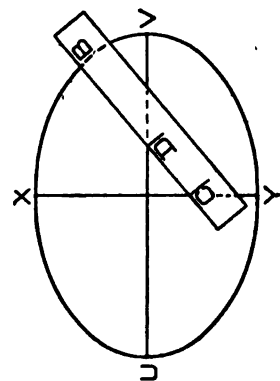
Problem 10



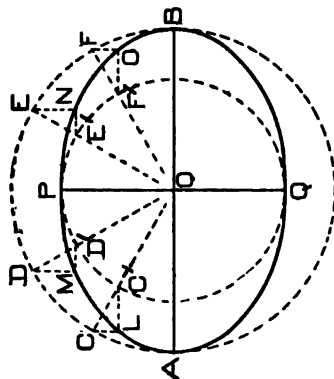
Problem 11



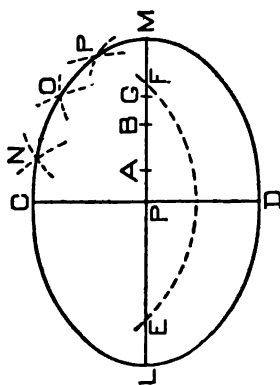
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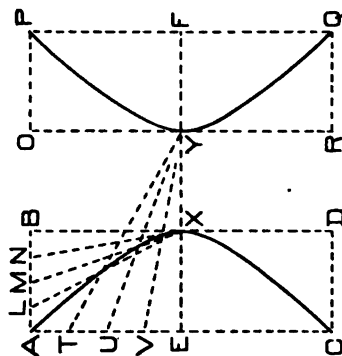
Problem 21



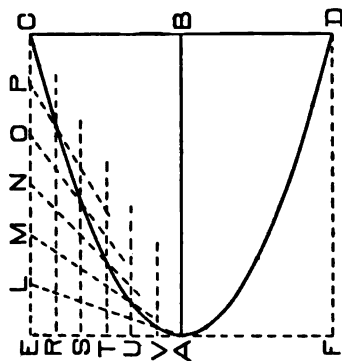
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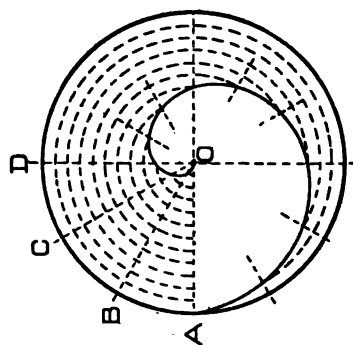
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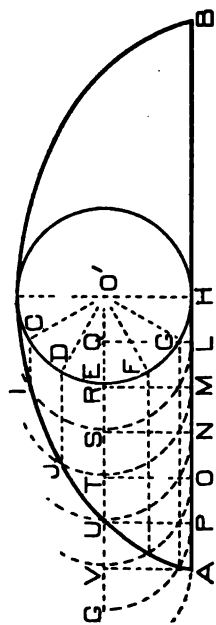
Problem 24



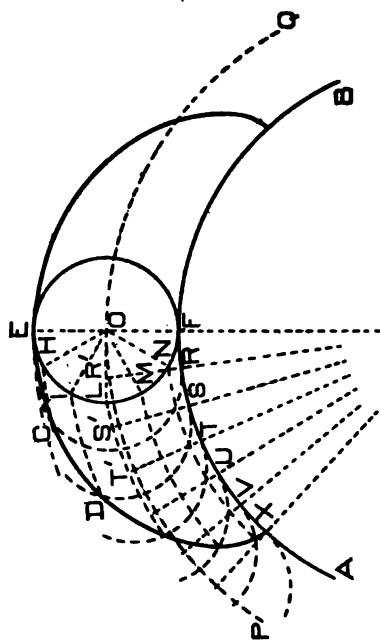
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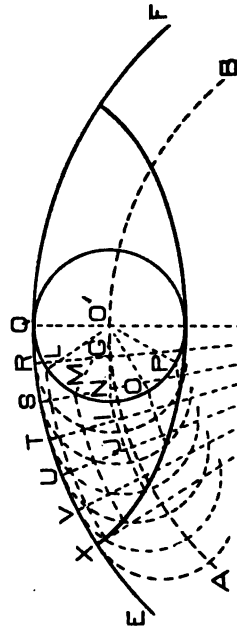
Problem 22



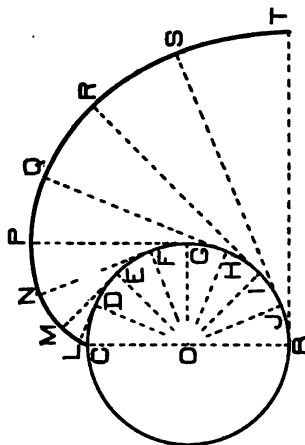
Problem 25



Problem 26



Problem 27



Problem 28

SECTION 3.

MECHANICAL DRAWING.

PART III.

PROJECTIONS.

Orthographic Projection is the art of representing an object upon two planes, at right angles to each other, by lines drawn from all points on the edges or contour perpendicular to these planes. The intersections of the perpendiculars with the planes give figures which are called projections of the object.

The two planes are called *planes of projection*, or *coördinate planes*, one being vertical and the other horizontal, as shown in Fig. 1. These planes are sometimes designated V and H respectively. The intersection of V and H is known as the ground line, or G L.

If a in Fig. 1 is a point in space, and a perpendicular is drawn to the vertical plane, the point a^v will be the projection of the point on the vertical plane, and in a similar way a^h will be the projection of a on the horizontal plane. The line B has its vertical projection at B^v , and its horizontal projection at B^h . Instead

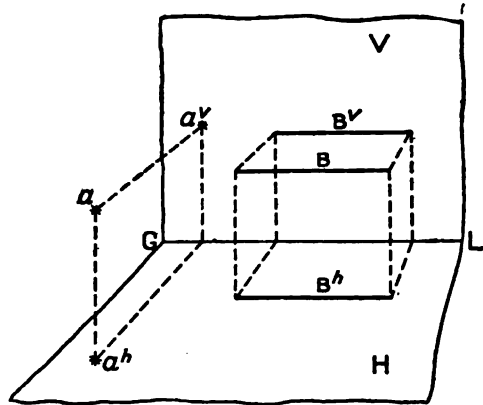


Fig. 1.

of *horizontal projection* and *vertical projection*, the terms **plan** and **elevation** are commonly used. It will be seen from the figure that the plan of a point or line is directly underneath on the H plane, and the elevation directly behind on the V plane.

Suppose in Fig. 2 a cube one inch on a side be placed with the top horizontal and the front face parallel to the vertical plane. Then the plan will be a one-inch square, and the elevation also a one-inch square. In general the plan is a representation of the *top* of the object, and the elevation a view of the *front*. The plan then is a top view, and the elevation a front view. Since the

plan is directly below the object, and the elevation directly behind, it follows that in actual drawing the plan must be vertically below the elevation, point for point. This is one of the fundamental principles of projection, and should be thoroughly understood.

The projection of a point can never be anything but a point. By referring to Fig. 1 it is clear that the height of a above the horizontal plane is equal to the distance of a^v above the ground

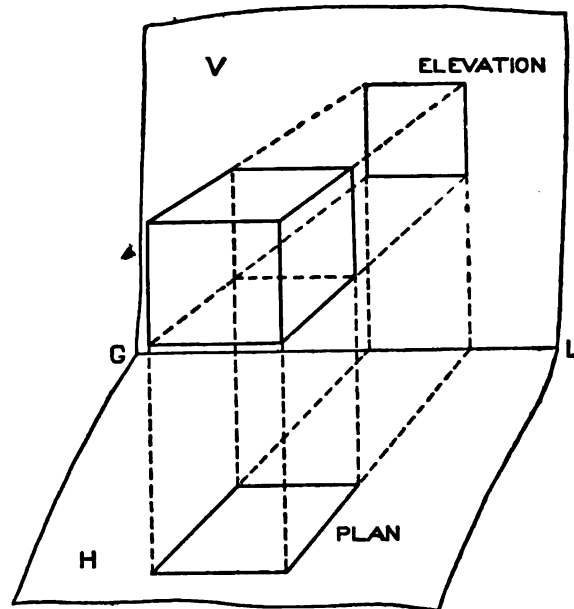


Fig. 2.

line, and the distance of a in front of the vertical plane is equal to the distance of a^h in front of the ground line. Applying this principle to Fig. 3, the point represented by a^v and a^h must be a point $\frac{3}{4}$ inch above H and 1 inch in front of V.

All points on an object at the same height must appear in elevation at the same distance above the ground line. If numbers 1, 2, 3 and 4 on the plan indicate the top corners of the cube, then these four points, being at the same height, must be shown in elevation at the same height and at the top, $\frac{4}{1}$ and $\frac{3}{2}$. The top of the cube, 1, 2, 3, 4, is shown in elevation as the straight line

$\frac{4}{1} - \frac{3}{2}$. This illustrates the fact that if a surface is perpendicular to either plane of projection, its projection on that plane is simply a line; a straight line if the surface is plane, a curved line if the surface is curved. From the same figure it is seen that the top edge of the cube, 1 4, has for its projection on the vertical plane

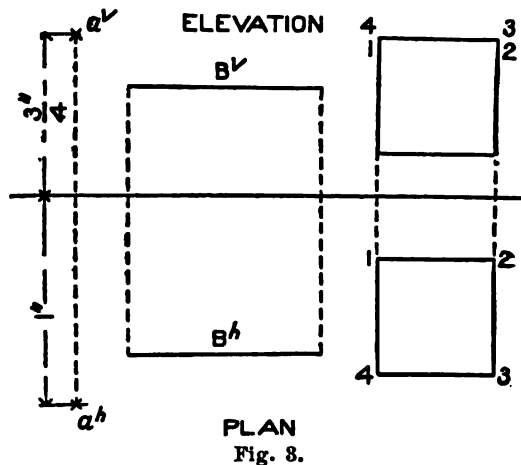


Fig. 8.

the point $\frac{4}{1}$, the principle of which is stated in this way: If a straight line is perpendicular to either V or H, its projection on that plane is a point, and on the other plane is a line equal in length to the line itself, and perpendicular to the ground line.

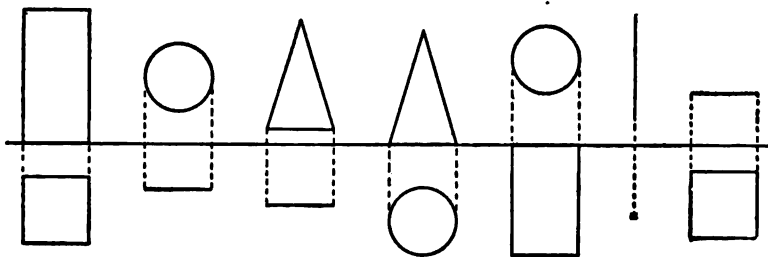


Fig. 4.

Fig. 4 is given as an exercise to help to show clearly the idea of plan and elevation. The student should answer the following question for himself: What does each of these projections represent?

Suppose in Fig. 5, that it is desired to construct the projections of a prism $1\frac{1}{2}$ in. square, and 2 in. long, standing on one end on the horizontal plane, two of its faces being parallel to the vertical plane. In the first place, as the top end of the prism is a square, the top view or plan will be a square of the same size, that is, $1\frac{1}{2}$ in. Then since the prism is placed parallel to and in front of the vertical plane the plan, $1\frac{1}{2}$ in. square, will have two edges parallel to the ground line. As the front face of the prism

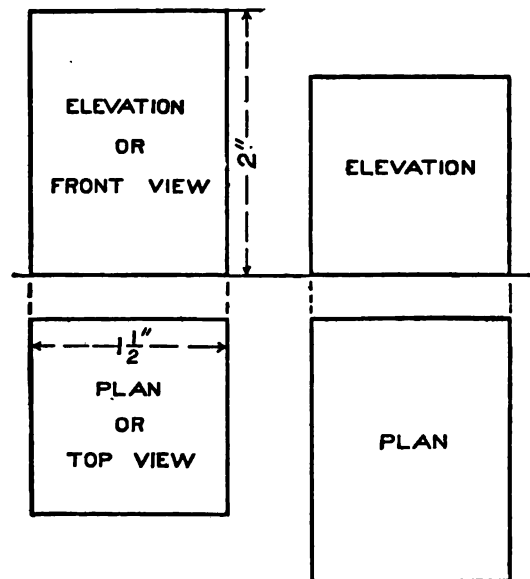


Fig. 5.

is parallel to the vertical plane its projection on V will be a rectangle, equal in length and width to the length and width respectively of the prism, and as the prism stands with its base on H, the elevation, showing height above H, must have its base on the ground line. Observe carefully that points in elevation are vertically over corresponding points in plan.

The second drawing in Fig. 5 represents a prism of the same size lying on one side on the horizontal plane, and with the ends parallel to V.

The principles which have been used thus far may be stated as follows, —

1. If a line or point is on either plane, its other projection must be in the ground line.

2. Height above H is shown in elevation as height above the ground line, and distance in front of the vertical plane is shown in plan as distance from the ground line.

3. If a line is parallel to either plane, its actual length is shown on that plane, and its other projection is parallel to the ground line. A line oblique to either plane has its projection on that plane shorter than the line itself, and its other projection oblique to the ground line.

4. A plane surface if parallel to either plane, is shown on

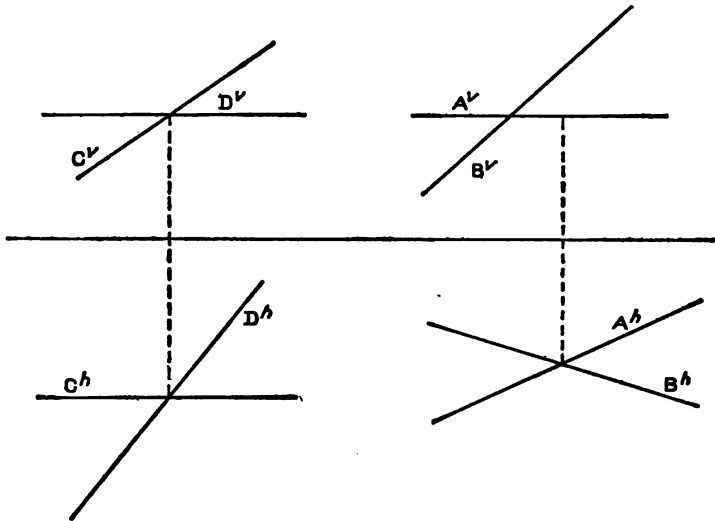


Fig. 6.

Fig. 7.

that plane in its true size and shape; if oblique it is shown smaller than the true size, and if perpendicular it is shown as a straight line. Lines parallel in space must have their V projections parallel to each other and also their H projections.

If two lines intersect, their projections must cross, since the point of intersection of the lines is a point on both lines, and therefore the projections of this point must be on the projections of both lines, or at their intersection. In order that intersecting lines may be represented, the vertical projections must intersect in a point vertically above the intersection of the horizontal pro-

jections. Thus Fig. 6 represents two lines which do intersect as C^v crosses D^v at a point vertically above the intersection of C^h and D^h . In Fig. 7, however, the lines do not intersect since the intersections of their projections do not lie in the same vertical line.

In Fig. 8 is given the plan and elevation of a square pyramid standing on the horizontal plane. The height of the pyramid is the distance $A B$. The slanting edges of the pyramid, $A C$, $A D$, etc., must be all of the same length, since A is directly above the center of the base.

What this length is, however, does not appear in either projection, as these edges are not parallel to either V or H .

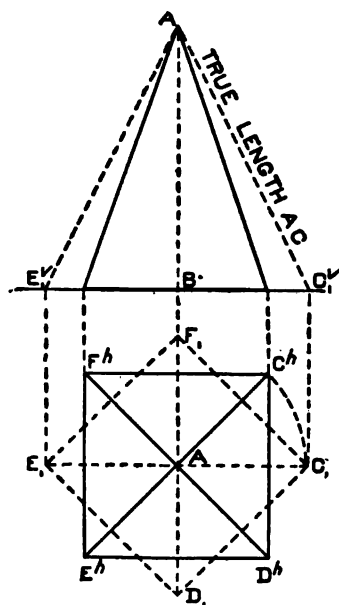


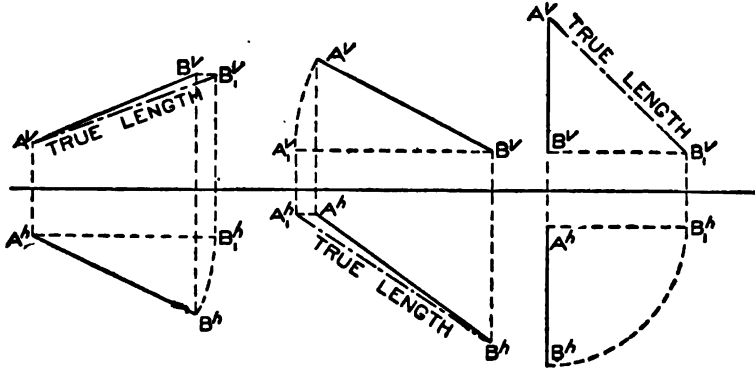
Fig. 8.

Suppose that the pyramid be turned around into the dotted position $C_1 D_1 E_1 F_1$, where the horizontal projections of two of the slanting edges, $A C_1$ and $A E_1$, are parallel to the ground line. These two edges, having their horizontal projections parallel to the ground line, are now parallel to V , and therefore their new vertical projections will show their true lengths. The base of the pyramid is still on H , and therefore is projected on V in the ground line. The apex is in the same place as before, hence the vertical projection of

the pyramid in its new position is shown by the dotted lines. The vertical projection $A C_1^v$ is the true length of edge $A C$. Now if we wish to find simply the true length of $A C$, it is unnecessary to turn the whole pyramid around, as the one line $A C$ will be sufficient.

The principle of finding the true length of lines is this, and can be applied to any case: Swing one projection of the line parallel to the ground line, using one end as center. On the other projection the moving end remains at the same distance from the ground line, and of course vertically above or below the same end in its parallel position. This new projection of the line shows its true length. See the three Figures at the top of page 9.

Third plane of projection or profile plane. A plane perpendicular to both co-ordinate planes, and hence to the ground line, is



called a *profile plane*. This plane is vertical in position, and may be used as a plane of projection. A projection on the profile plane is called a *profile view*, or *end view*, or sometimes *edge view*, and is often required in machine or other drawing when the plan and elevation do not sufficiently give the shape and dimensions.

A projection on this plane is found in the same way as on the

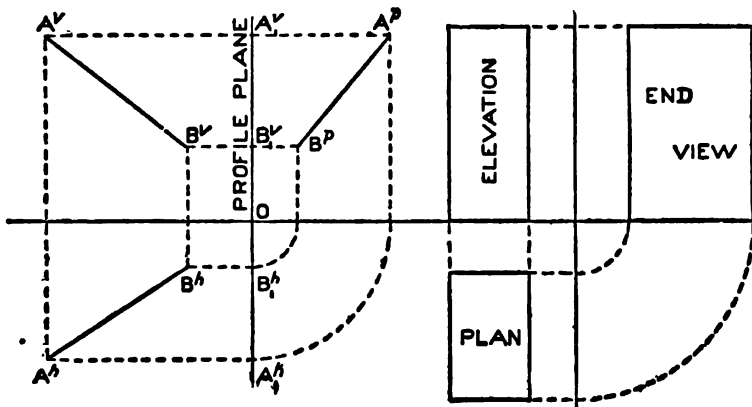


Fig. 9.

V plane, that is, by perpendiculars drawn from points on the object.

Since, however, the profile plane is perpendicular to the ground line, it will be seen from the front and top simply as a

straight line; in order that the size and shape of the profile view may be shown, the profile plane is revolved into V using its intersection with the vertical plane as the axis.

Given in Fig. 9, the line A B by its two projections $A^v B^v$ and $A^h B^h$, and given also the profile plane. Now by projecting the line on the profile by perpendiculars, the points $A_1^v B_1^v$ and $B_1^h A_1^h$ are found. Revolving the profile plane like a door on its hinges, all points in the plane will move in horizontal circles, so the horizontal projections A_1^h and B_1^h will move in arcs of circles with O as center to the ground line, and the vertical projections B_1^v and A_1^v will move in lines parallel to the ground line to positions directly above the revolved points in the ground line, giving the profile view of the line $A^p B^p$. Heights, it will be seen, are the same in profile view

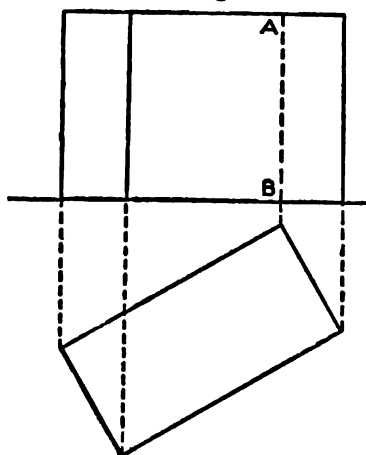


Fig. 10.

as in elevation. By referring to the rectangular prism in the same figure, we see that the elevation gives vertical dimensions and those parallel to V, while the end view shows vertical dimensions and those perpendicular to V. The profile view of any object may be found as shown for the line A B by taking one point at a time.

In Fig. 10 there is represented a rectangular prism or block, whose length is twice the width. The elevation shows its height. As the prism is placed at

an angle, three of the vertical edges will be visible, the fourth one being invisible.

In mechanical drawing lines or edges which are invisible are drawn *dotted*. The edges which in projection form a part of the outline or contour of the figure must always be visible, hence always *full lines*. The plan shows what lines are visible in elevation, and the elevation determines what are visible in plan. In Fig. 10, the plan shows that the dotted edge A B is the back edge, and in Fig. 11, the dotted edge C D is found, by looking at the elevation, to be the lower edge of the triangular prism. In general,

if in elevation an edge projected *within* the figure is a back edge, it must be dotted, and in plan if an edge projected within the outline is a lower edge it is dotted.

Fig. 12 is a circular cylinder with the length vertical and

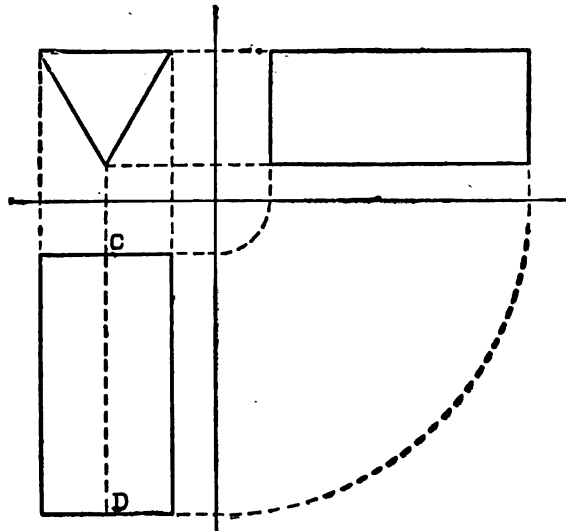


Fig. 11.

with a hole part way through as shown in elevation. Fig. 13 is plan, elevation and end view of a triangular prism with a square hole from end to end. The plan and elevation alone would be insufficient to determine positively the shape of the hole, but the end view shows at a glance that it is square.

In Fig. 14 is shown plan and elevation of the frustum of a square pyramid, placed with its base on the horizontal plane. If the frustum is turned through 30° , as shown in the plan of Fig. 15, the top view or plan must still be the same shape and size, and as the frustum has not been raised or lowered, the heights of all points must appear the same in elevation as before in Fig. 14. The elevation is easily found by projecting points up from the plan, and projecting the height of the top horizontally across from the first elevation.

The same principle is further illustrated in Figs. 16 and 17. The elevation of Fig. 16 shows a square prism resting on one edge, and raised up at an angle of 30° on the right-hand side. The

plan gives the width or thickness, $\frac{1}{8}$ in. Notice that the length of the plan is greater than 2 in. and that varying the angle at

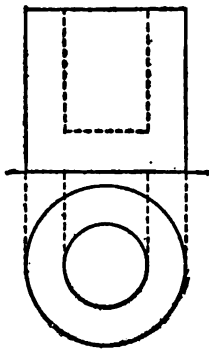


Fig. 12.

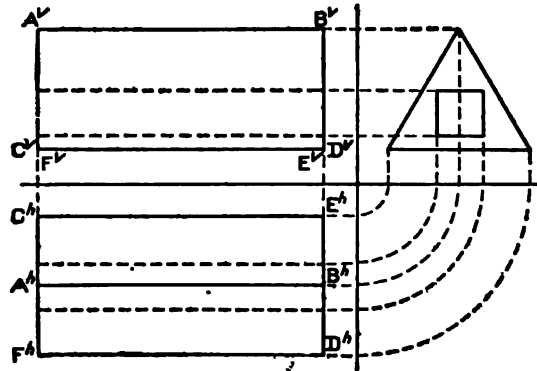


Fig. 13.

which the prism is slanted would change the length of the plan. Now if the prism be turned around through any angle with the vertical plane, the lower edge still being on H, and the inclination

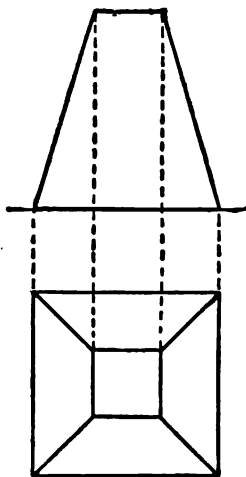


Fig. 14.

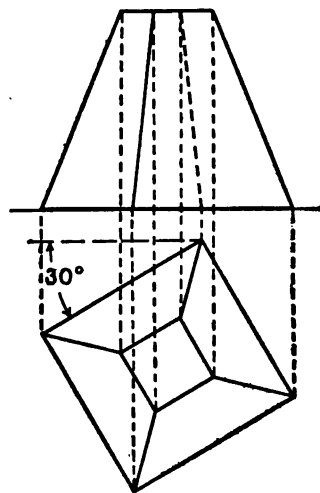


Fig. 15.

of 30° with H remaining the same, the plan must remain the same size and shape.

If the angle through which the prism be turned is 45° , we

have the second plan, exactly the same shape and size as the first. The elevation is found by projecting the corners of the prism ver-

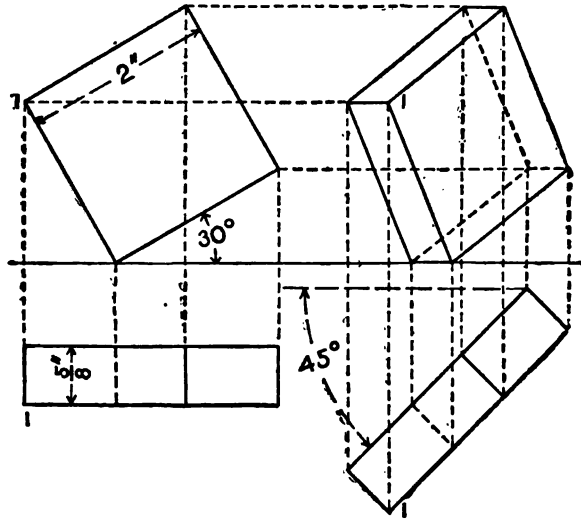


Fig. 16.

tically up to the heights of the same points in the first elevation. All the other points are found in the same way as point No. 1.

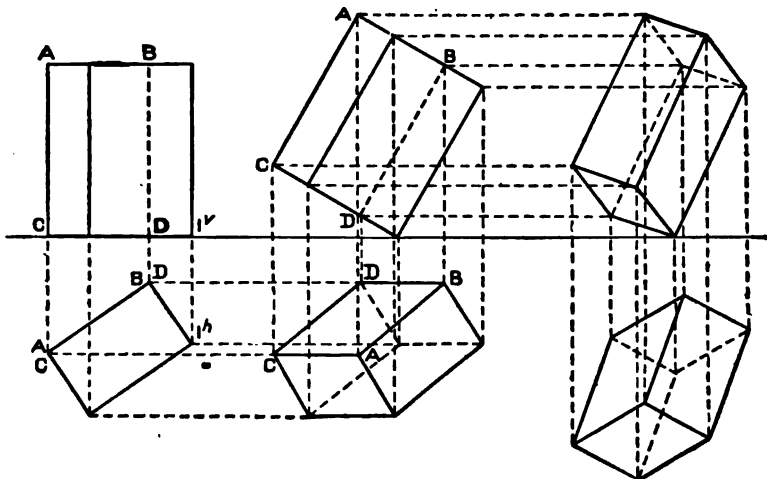


Fig. 17.

Three positions of a rectangular prism are shown in Fig. 17. In the first view, the prism stands on its base, its axis therefore

is parallel to the vertical plane. In the second position, the axis is still parallel to V and one corner of the base is on the horizontal plane. The prism has been turned as if on the line $1^h 1^v$ as an axis, so that the inclination of all the faces of the prism to the vertical plane remains the same as before. That is, if in the first figure the side A B C D makes an angle of 30° with the vertical, the same side in the second position still makes 30° with the ver-

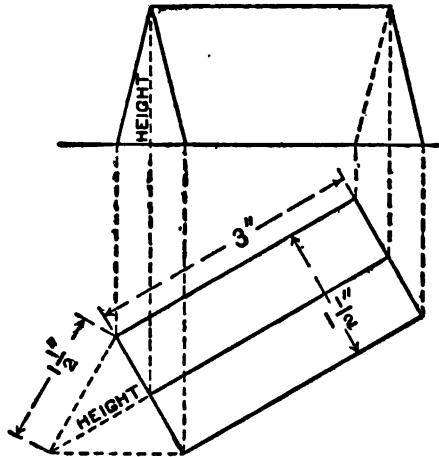


Fig. 18.

tical plane. Hence the elevation of No. 2 is the same shape and size as in the first case. The plan is found by projecting the corners down from the elevation to meet horizontal lines projected across from the corresponding points in the first plan. The third position shows the prism with all its faces and edges making the same angles with the horizontal as in the second position, but with the plan at a different angle with the ground line. The plan then is the same shape and size as in No. 2, and the elevation is found by projecting up to the same heights as shown in the preceding elevation. This principle may be applied to any solid, whether bounded by plane surfaces or curved.

This principle as far as it relates to heights, is the same that was used for profile views. An end view is sometimes necessary before the plan or elevation of an object can be drawn. Suppose that in Fig. 18 we wish to draw the plan and elevation of a triangular prism 3" long, the end of which is an equilateral triangle

$1\frac{1}{2}$ " on each side. The prism is lying on one of its three faces on H, and inclined toward the vertical plane at an angle of 30° . We

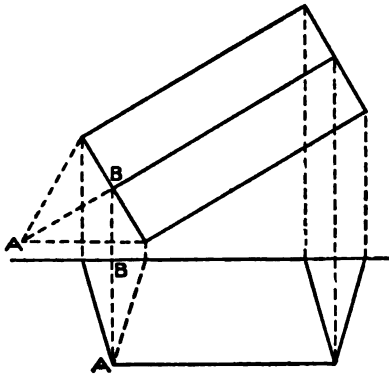


Fig. 19.

are able to draw the plan at once, because the width will be $1\frac{1}{2}$ inches, and the top edge will be projected half way between the other two. The length of the prism will also be shown. Before we can draw the elevation, we must find the height of the top edge. This height, however, must be equal to the altitude of the triangle forming the end of the prism. All that is necessary, then, is to construct an equilateral

triangle $1\frac{1}{2}$ " on each side, and measure its altitude.

A very convenient way to do this is shown in the figure by laying one end of the prism down on H. A similar construction is shown in Fig. 19, but with one face of the prism on V instead of on H.

In all the work thus far the plan has been drawn below and the elevation above. This order is sometimes inverted and the plan put above the elevation, but the plan still remains a top view no matter where placed, so that after some practice it makes but little difference to the draughtsman which method is employed.

SHADE LINES.

It is often the case in machine drawing that certain lines or edges are made heavier than others. These heavy lines are called shade lines, and are used to improve the appearance of the drawing, and also to make clearer in some cases the shape of the object. The shade lines are not put on at random, but according to some system. Several systems are in use, but only that one which seems most consistent will be described. The shade lines are lines or edges separating light faces from dark ones, assuming the light always to come in a direction parallel to the dotted diagonal of the cube shown in Fig. 20. The direction of the light, then, may be represented on H by a line at 45° running

backward to the right and on V by a 45° line sloping downward and to the right. Considering the cube in Fig. 20, if the light comes in the direction indicated, it is evident that the front, left-hand side and top will be light, and the bottom, back and right-hand side dark. On the plan, then, the shade lines will be the back edge 1 2 and the right-hand edge 2 3, because these edges are between light faces and dark ones. On the elevation, since the front is light, and the right-hand side and bottom dark, the edges 3 7 and 8 7 are shaded. As the direction of the light is represented on the plan by 45° lines and on the elevation also by 45° lines,

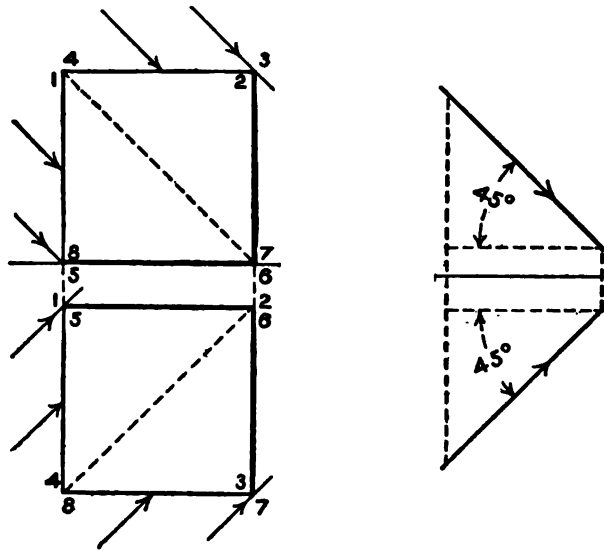


Fig. 20.

we may use the 45° triangle with the T-square to determine the light and dark surfaces, and hence the shade lines. If the object stands on the horizontal plane, the 45° triangle is used on the plan, as shown in Fig. 21, but if the length is perpendicular to the vertical plane, the 45° triangle is used on the elevation, as shown in Fig. 22. This is another way of saying that the 45° triangle is used on that projection of the object which shows the end. By applying the triangle in this way we determine the light and dark surfaces, and then put the shade lines between them. Dotted lines, however, are never shaded, so if a line which is between a light and a dark surface is invisible it is not

shaded. In Fig. 21 the plan shows the end of the solid, hence the 45° triangle is used in the direction indicated by the arrows.

This shows that the light strikes the left-hand face, but not the back or the right-hand. The top is known to be light with-

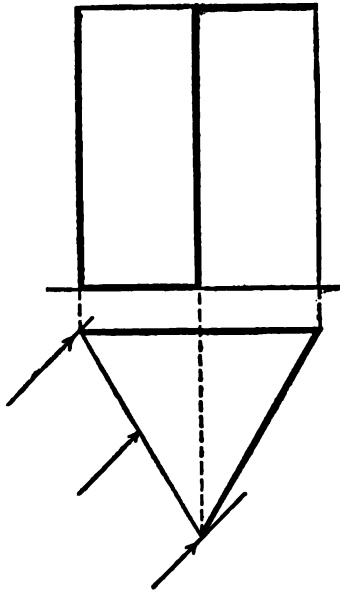


Fig. 21.

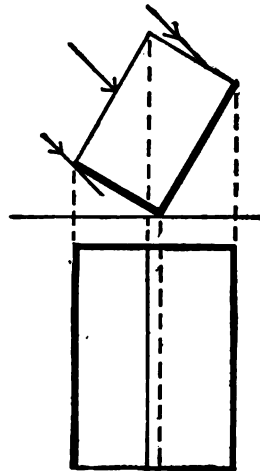


Fig. 22.

out the triangle, as the light comes downward, so the shade edges on the plan are the back and right-hand. On the elevation two faces of the prism are visible; one is light, the other dark, hence the edge between is shaded. The left-hand edge, being between a light face and a dark one is a shade line. The right-hand face is dark, the top of the prism is light, hence the upper edge of this face is a shade line. The right-hand edge is not shaded, because by referring to the plan, it is seen to be between two dark surfaces. In shading a cylinder or a cone the same rule is followed, the only difference being that as the surface is curved, the light is tangent, so an element instead of an edge marks the separation of the dark from the light, and is *not* shaded. The elements of a cylinder or cone should *never* be shaded, but the bases may. In Fig. 23, Nos. 3 and 4, the student should carefully notice the difference between the shading of the cone and cylinder.

If in No. 4 the cone were inverted, the opposite half of the base would be shaded, for then the base would be light, whereas it is now dark. In Nos. 7 and 8 the shade lines of a cylinder and a circular hole are contrasted.

In No. 7 it is clear that the light would strike inside on the further side of the hole, commencing half way where the 45° lines

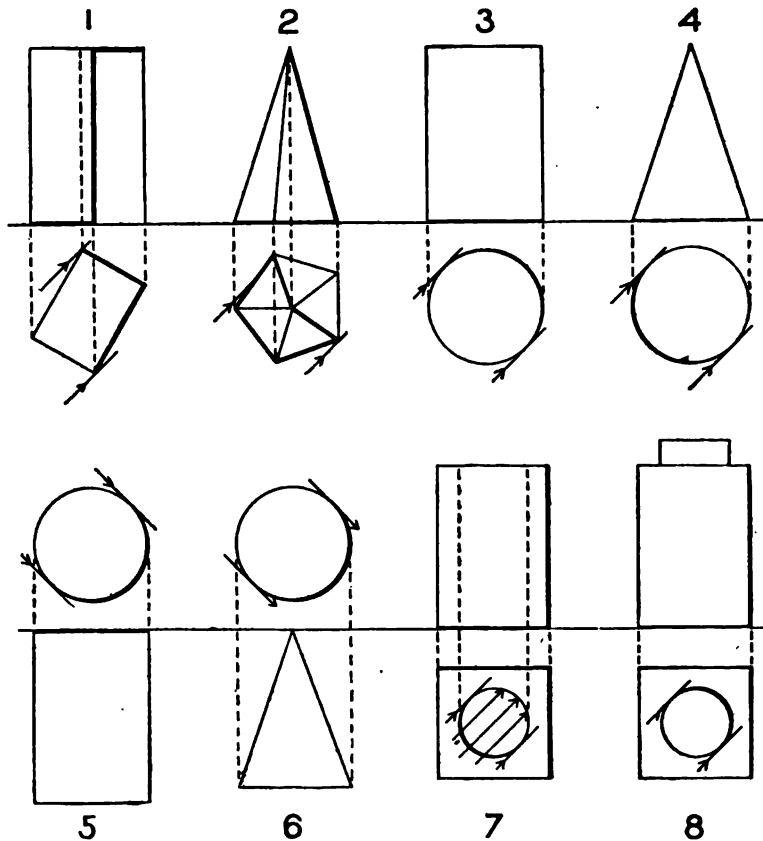


Fig. 23.

are tangent. The other half of the inner surface would be dark, hence the position of the shade line. The shade line then enables us to tell at a glance whether a circle represents a hub or boss, or depression or hole. Fig. 24 represents plan, elevation and profile view of a square prism. Here as before, the view showing the end is the one used to determine the light and dark surfaces, and then the shade lines put in accordingly.

In putting on the shade lines, the extra width of line is put *inside* the figure, not outside. In shading circles, the shade line is made of varying width, as shown in the figures. The method of obtaining this effect by the compass is to keep the same radius, but to change the center slightly in a direction parallel to the rays of light, as shown at A and B in No. 2 of Fig. 24.

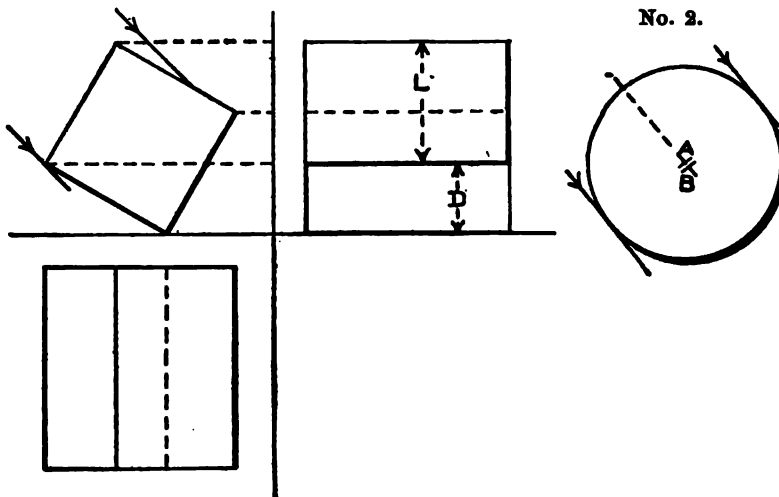


Fig. 24.

INTERSECTION AND DEVELOPMENT.

If one surface meets another at some angle, an intersection is produced. Either surface may be plane, or curved. If both are plane, the intersection is a straight line; if one is curved, the intersection is a curve, except in a few special cases; and if both are curved, the intersection is usually curved.

In the latter case, different parts of the curve often lie in different planes. If all points of any curve lie in the same plane, it is called a plane curve. A plane intersecting a curved surface must always give either a plane curve or a straight line.

In Fig. 25 a square pyramid is cut by the horizontal plane A. This plane cuts from the pyramid a four-sided figure, the four corners of which will be the points where A cuts the four slanting edges of the solid. The plane intersects edge *o b* at point 4^v in elevation. This point must be found in plan vertically below on

the horizontal projection of line $o b$, that is, at point 4^h . Edge $o e$ is directly in front of $o b$, so is shown in elevation as the same line, and plane A intersects $o e$ at point 1^v in elevation, found in plan at 1^h . Points 3 and 2 are obtained in the same way. The intersection is shown in plan as the square $1\ 2\ 3\ 4$, which is also its true size as it is parallel to the horizontal plane. In a

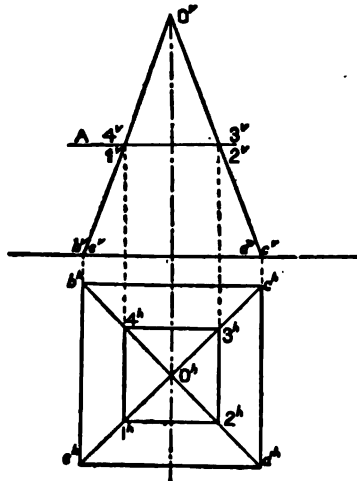


Fig. 25.

similar way the sections are found in Figs. 26 and 27. It will be seen that in these three cases where the planes are parallel to the bases, the sections are of the same shape as the bases, and have their sides parallel to the edges of the bases.

It is an invariable rule that when a solid is cut by a plane parallel to its base, the section is a figure of the same shape as the base. If then in Fig. 28 a circular cone is intersected by a plane parallel to the base the section must be a circle, the center of

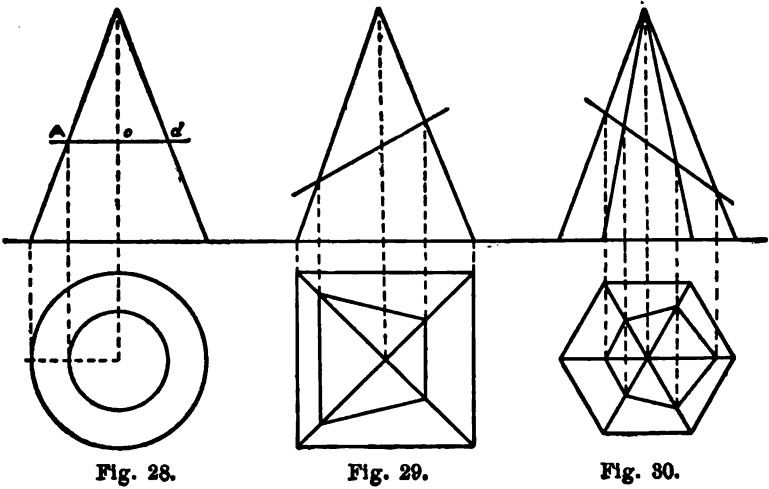
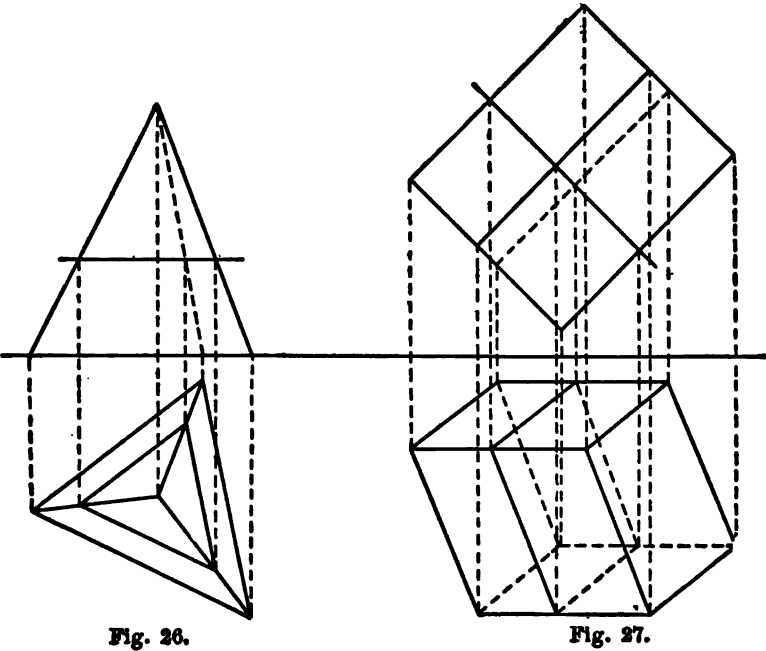
which in plan coincides with the apex. The radius must equal $o d$.

In Figs. 29 and 30 the cutting plane is not parallel to the base, hence the intersection will not be of the same shape as the base. The sections are found, however, in exactly the same manner as in the previous figures, by projecting the points where the plane intersects the edges in elevation on to the other view of the same line.

INTERSECTION OF PLANES WITH CONES OR CYLINDERS.

Sections cut by a plane from a cone have already been defined as *conic sections*. These sections may be either of the following: two straight lines, circle, ellipse, parabola, hyperbola. All except the parabola and hyperbola may also be cut from a cylinder.

Methods have previously been given for constructing the



ellipse, parabola and hyperbola without projections; it will now be shown that they may be obtained as actual intersections.

In Fig. 31 the plane cuts the cone obliquely. To find points on the curve in plan take a series of horizontal planes

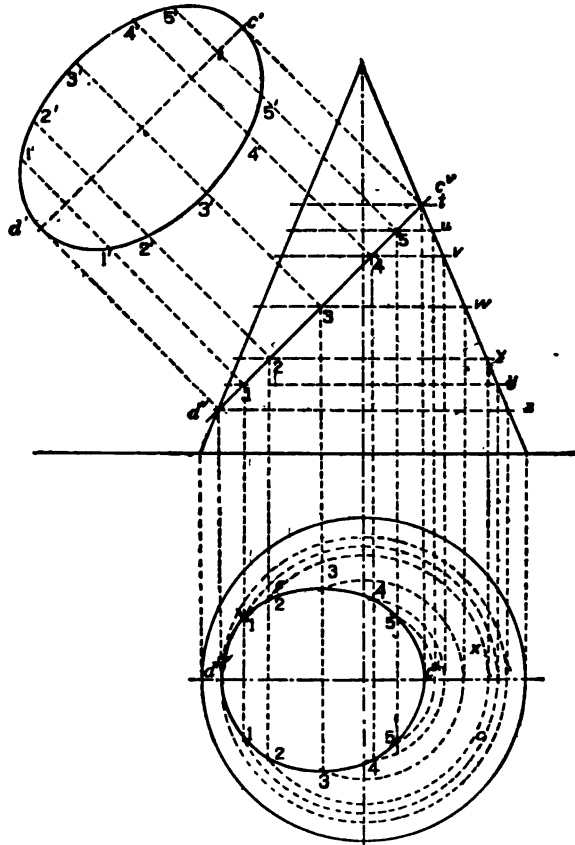


Fig. 31.

$x y z$ etc., between points c^v and d^v . One of these planes, as w , should be taken through the center of $c d$. The points c and d must be points on the curve, since the plane cuts the two contour elements at these points. The horizontal projections of the contour elements will be found in a horizontal line passing through the center of the base; hence the horizontal projection of c and d will be found on this center line, and will be the extreme ends of the curve.

The plane x cuts the surface of the cone in a circle, as it is parallel to the base, and the diameter of the circle is the distance between the points where x crosses the two contour elements. This circle, lettered x on the plan, has its center at the horizontal projection of the apex. The circle x and the curve cut by the plane are both on the surface of the cone, and their vertical projections intersect at the point 2. Also the circle x and the curve must cross twice, once on the front of the cone and once on the back. Point 2 then represents two points which are shown in plan directly beneath on the circle x , and are points on the required intersection. Planes y and z , and as many more as may be necessary to determine the curve accurately, are used in the same way. The curve found is an ellipse. The student will readily see that the true size of this ellipse is not shown in the plan, for the plane containing the curve is not parallel to the horizontal.

In order to find the actual size of the ellipse, it is necessary to place its plane in a position parallel either to the vertical or to the horizontal. The actual length of the long diameter of the ellipse must be shown in elevation, $c^v d^v$, because the line is parallel to the vertical plane. The plane of the ellipse then may be revolved about $c^v d^v$ as an axis until it becomes parallel to V , when its true size will be shown. For the sake of clearness of construction, $c^v d^v$ is imagined moved over to the position $c' d'$, parallel to $c^v d^v$. The lines 1—1, 2—2, 3—3 on the plan show the true width of the ellipse, as these lines are parallel to H , but are projected closer together than their actual distances. In elevation these lines are shown as the points 1, 2, 3, at their true distance apart. Hence if the ellipse is revolved around its axis $c^v d^v$, the distances 1—1, 2—2, 3—3 will appear perpendicular to $c^v d^v$, and the true size of the figure be shown. This construction is made on the left, where 1'—1', 2'—2' and 3'—3' are equal in length to 1—1, 2—2, 3—3 on the plan.

In Fig. 82 a plane cuts a cylinder obliquely. This is a simpler case, as the horizontal projection of the curve coincides with the base of the cylinder. To obtain the true size of the section, which is an ellipse, any number of points are assumed on the plan and projected up on the cutting plane, at 1, 2, 3, etc.

The lines drawn through these points perpendicular to 1 7 are made equal in length to the corresponding distances 2'—2', 3'—3' etc., on the plan.

If a cone is intersected by a plane which is parallel to only one of the elements, as in Fig. 33, the resulting curve is the parabola, the construction of which is exactly similar to that for the ellipse as given in Fig. 31. If the intersecting plane is parallel to more than one element, or is parallel to the axis of the cone, a hyperbola is produced.

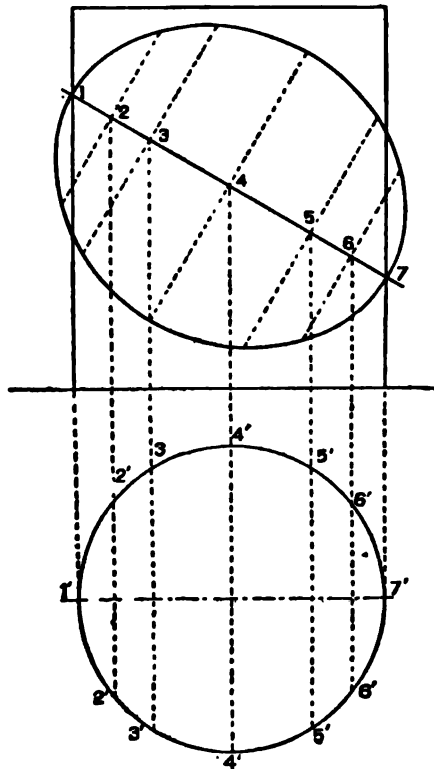


Fig. 32.

In Fig. 34, the vertical plane A is parallel to the axis of the cone. In this instance the curve when found will appear in its true size, as plane A is parallel to the vertical. Observe that the highest point of the curve is found by drawing the circle X on the plan tangent to the given plane. One of the points where this circle crosses the diameter is projected up to the contour element of the

cone, and the horizontal plane X drawn. Intermediate planes Y, Z, etc., are chosen, and corresponding circles drawn in plan. The points where these circles are crossed by the plane A are points on the curve, and these points are projected up to the elevation on the planes Y, Z, etc.

DEVELOPMENTS.

The development of a surface is the true size and shape of the surface extended or spread out on a plane. If the surface to be developed is of such a character that it may be flattened out

without tearing or folding, we obtain an exact development, as in case of a cone or cylinder, prism or pyramid. If this cannot be done, as with the sphere, the development is only approximate.

In order to find the development of the rectangular prism in Fig 35, the back face, 1 2 7 6, is supposed to be placed in contact

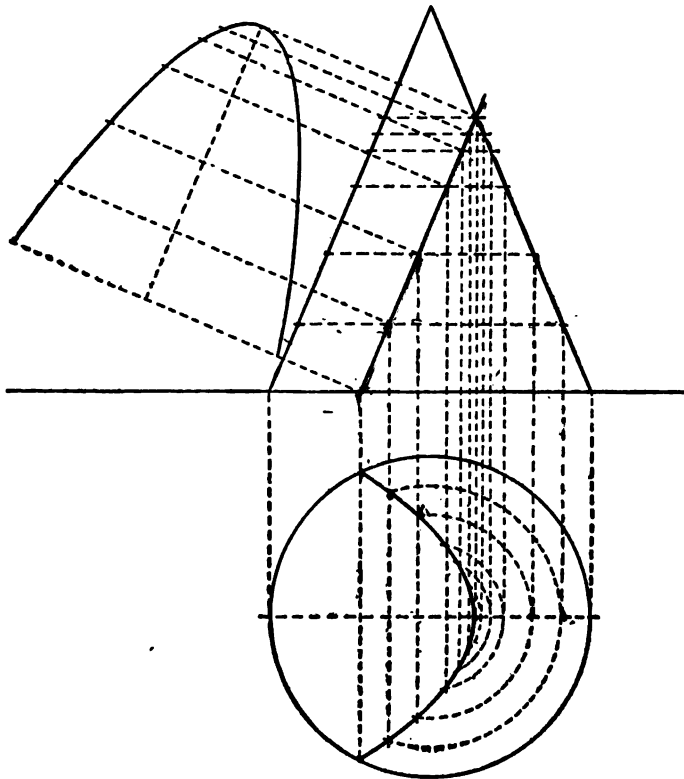


Fig. 38.

with some plane, then the prism turned on the edge 2 7 until the side 2 3 8 7 is in contact with the same plane, then this continued until all four faces have been placed on the same plane. The rectangles 1 4 3 2 and 6 7 8 5 are for the top and bottom respectively. The development then is the exact size and shape of a covering for the prism. If a rectangular hole is cut through the prism, the openings in the front and back faces will be shown in the development in the centers of the two broad faces.

The development of a right prism, then, consists of as many

rectangles joined together as the prism has sides, these rectangles being the exact size of the faces of the prism, and in addition two polygons the exact size of the bases. It will be found helpful in developing a solid to number or letter all of the corners on the

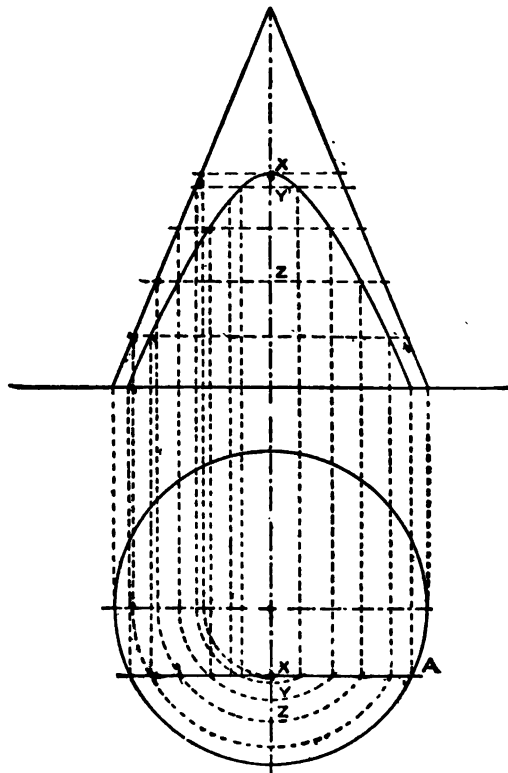


Fig. 34.

projections, then designate each face when developed in the same way as in the figure.

If a cone be placed on its side on a plane surface, one element will rest on the surface. If now the cone be rolled on the plane, the vertex remaining stationary, until the same element is in contact again, the space rolled over will represent the development of the convex surface of the cone. A, Fig. 36, is a cone cut by a plane parallel to the base. In B, let the vertex of the cone be

placed at V, and one element of the cone coincide with V A I. The length of this element is taken from the elevation A, of either contour element. All of the elements of the cone are of the same length, so when the cone is rolled each point of the base as it touches the plane will be at the same distance from the vertex. From this it follows that the development of the base will be the arc of a circle of radius equal to the length of an element. To find the length of this arc which is equal to the distance around the base, divide the plan of the circumference of the base into any number of equal parts, as twelve, then

with the length of one of these parts as radius, lay off twelve spaces, 1....13, join 1 and 13 with V, and the sector is the development of the cone from vertex to base. To represent on the development

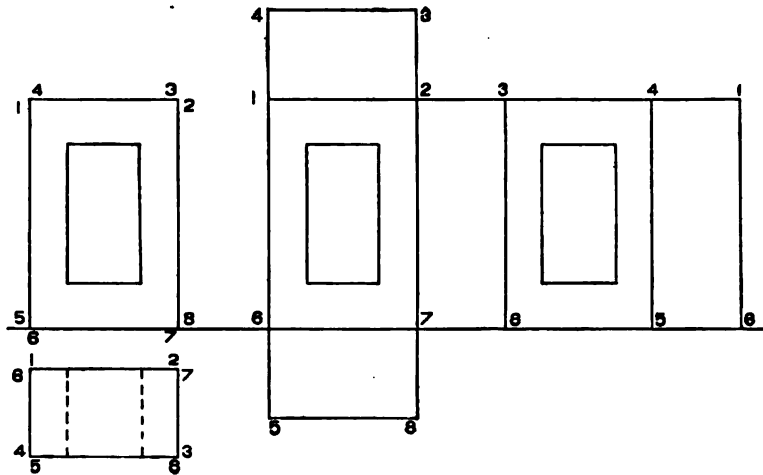


Fig. 35.

the circle cut by the section plane, take as radius the length of the element from the vertex to D, and with V as center describe

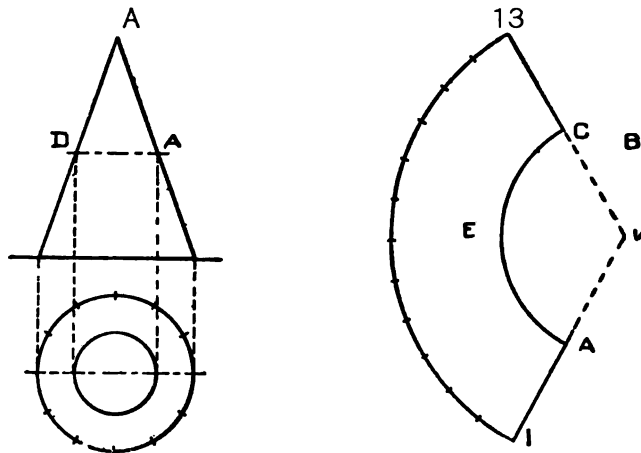


Fig. 36.

an arc. The development of the frustum of the cone will be the portion of the circular ring. This of course does not include the

development of the bases, which would be simply two circles the same sizes as shown in plan.

A and B, Fig. 37, represent the plan and elevation of a regular triangular pyramid and its development. If face C is placed on the plane its true size will be shown at C in the development. The true length of the base of triangle C is shown in the plan. The slanting edges, however, not being parallel to the vertical, are not shown in elevation in their true length. It becomes necessary then, to find the true length of one of these edges as shown in Fig. 6, after which the triangle may be drawn in its full size at C in the development. As the pyramid is regular, three equal triangles as shown developed at C, D and E, together with the base F, constitute the development.

If a right circular cylinder is to be developed, or rolled upon a plane, the elements, being parallel, will appear as parallel lines,

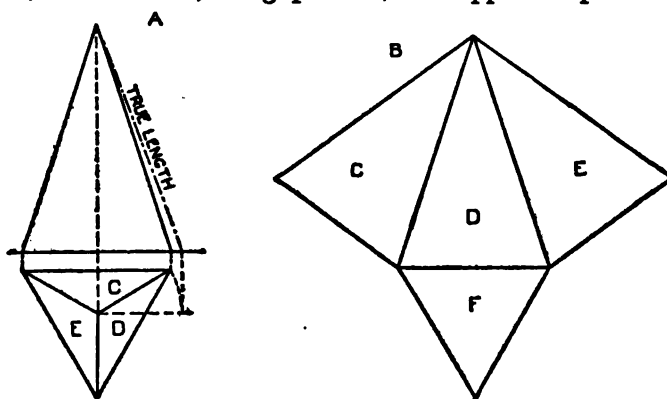


Fig. 37.

and the base, being perpendicular to the elements, will develop as a straight line perpendicular to the elements. The width of the development will be the distance around the cylinder, or the circumference of the base. The base of the cylinder in Fig. 38, is divided into twelve equal parts, 1 2 3, etc. Commencing at point 1 on the development these twelve equal spaces are laid along the straight line, giving the development of the base of the cylinder, and the total width. To find the development of the curve cut by the oblique plane, draw in elevation the elements corresponding to the various divisions of the base, and note the points

where they intersect the oblique plane. As we roll the cylinder beginning at point 1, the successive elements 1, 12, 11, etc., will appear at equal distances apart, and equal in length to the lengths of the same elements in elevation. Thus point number 10 on the development of the curve is found by projecting horizontally across from 10 in elevation. It will be seen that the curve is symmetrical, the half on the left of 7 being similar to that on the right. The development of any curve whatever on the surface of the cylinder may be found in the same manner.

The principle of cylinder development is used in laying out elbow joints, pipe ends cut off obliquely, etc. In Fig. 39 is shown plan and elevation of a three-piece elbow and collar, and develop-

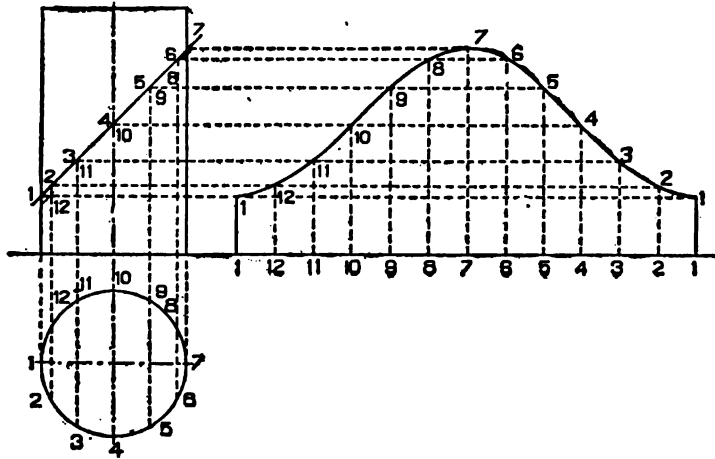


Fig. 38.

ments of the four pieces. In order to construct the various parts making up the joint, it is necessary to know what shape and size must be marked out on the flat sheet metal so that when cut out and rolled up the three pieces will form cylinders with the ends fitting together as required. Knowing the kind of elbow desired, we first draw the plan and elevation, and from these make the developments. Let the lengths of the three pieces A, B and C be the same on the upper outside contour of the elbow, the piece B at an angle of 45° ; the joint between A and B bisects the angle between the two lengths, and in the same way the joint between B and C. The lengths A and C will then be the same,

and one pattern will answer for both. The development of A is made exactly as just explained for Fig. 38, and this is also the development of C.

It should be borne in mind that in developing a cylinder we must always have a base at right angles to the elements, and if the cylinder as given does not have such a base, it becomes necessary to cut the cylinder by a plane perpendicular to the elements, and use the intersection as a base. This point must be clearly understood in order to proceed intelligently. A section at right angles to the elements is the only section which will unroll in a

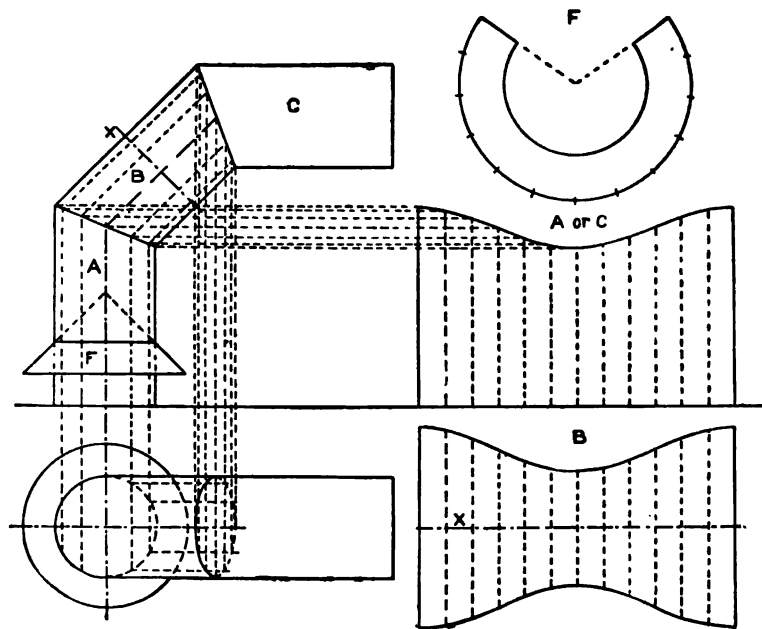


Fig. 39.

straight line, and is therefore the section from which we must work in developing other sections. As B has neither end at right angles to its length, the plane X is drawn at the middle and perpendicular to the length. B is the same diameter pipe as C and A, so the section cut by X will be a circle of the same diameter as the base of A, and its development is shown at X.

From the points where the elements drawn on the elevation of A meet the joint between A and B, elements are drawn on B,

which are equally spaced around B the same as on A. The spaces then laid off along X are the same as given on the plan of A. Commencing with the left-hand element in B, the length of the upper element between X and the top corner of the elbow is laid off above X, giving the first point in the development of the end of B fitting with C. The lengths of the other elements in the elevation of B are measured in the same way and laid off from X. The development of the other end of the piece B is laid off below X, using the same distances, since X is half way between the ends. The development of the collar is simply the development of the frustum of a cone, which has already been explained, Fig. 36. The joint between B and C is shown in plan as an ellipse, the construction of which the student should be able to understand from a study of the figure.

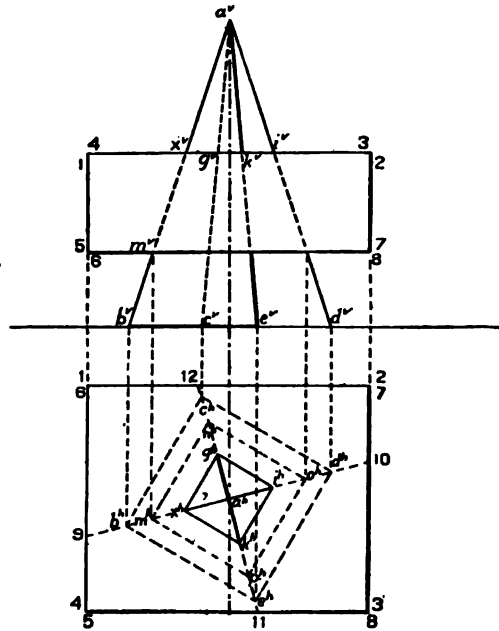


Fig. 40.

The intersection of a rectangular prism and pyramid is shown in Fig. 40. The base $b c d e$ of the pyramid is shown dotted in plan, as it is hidden by the prism. All four edges of the pyramid pass through the top of the prism, 1, 2, 3, 4. As the top of the prism is a horizontal plane, the edges of the pyramid are shown passing through the top in elevation at $x^v g^v k^v i^v$. These four points might be projected to the plan on the four edges of the pyramid; but it is unnecessary to project more than one, since the general principle applies here that if a cone, pyramid, prism or cylinder be cut by a plane parallel to the base, the section is a figure parallel and similar to the base. The one point x^v is therefore projected down to $a b$ in plan, giving x^h , and with this as

one corner, the square $x^h g^h i^h k^h$ is drawn, its sides parallel to the edges of the base. This square is the intersection of the pyramid with the top of the prism.

The intersection of the pyramid with the bottom of the prism is found in like manner, by taking the point where one edge of the pyramid as a^b passes through the bottom of the prism shown in elevation as point m^v , projecting down to m^h on $a^h b^h$, and drawing the square $m^h n^h o^h p^h$ parallel to the base of the pyramid. These two squares constitute the entire intersection of the two solids, the pyramid going through the bottom and coming out at the top of the prism. As much of the slanting edges of the

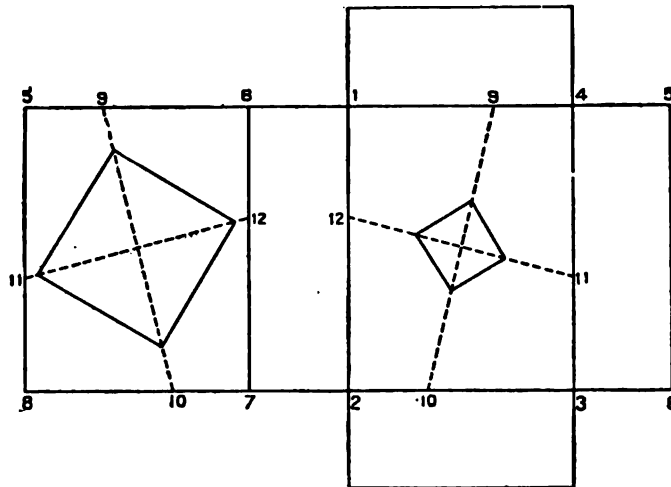


Fig. 41.

pyramid as are above the prism will be seen in plan, appearing as the diagonals of the small square, and the rest of the pyramid, being below the top surface of the prism, will be dotted in plan.

Fig. 41 is the development of the rectangular prism, showing the openings in the top and bottom surfaces through which the pyramid passed. The development of the top and bottom, back and front faces will be four rectangles joined together, the same sizes as the respective faces. Commencing with the bottom face 5 6 7 8, next would come the back face 6 1 2 7, then the top, etc. The rectangles at the ends of the top face 1 2 3 4 are the ends of the prism. These might have been joined on any other

face as well. Now find the development of the square in the bottom 5 6 7 8. As the size will be the same as in projection, it only remains to determine its position. This position, however, will have the same relation to the sides of the rectangle as in the plan. The center of the square in this case is in the center of the face. To transfer the diagonals of the square to the development, extend them in plan to intersect the edges of the prism in points 9, 10, 11 and 12. Take the distance from 5 to 9 along the edge 5 6, and lay it on the development from 5 along 5 6, giving point 9. Point 10 located in the same way and connected with 9, gives the position of one diagonal. The other diagonal is obtained in a similar way, then the square constructed on these diagonals. The same method is used for locating the small square on the top face.

If the intersection of a cylinder and prism is to be found, we may either obtain the points where elements of the cylinder pierce the prism, or where edges and lines parallel to edges on the surface of the prism cut the cylinder.

A series of parallel planes may also be taken cutting curves from the cylinder and straight lines from the prism; the intersections give points on the intersection of the two solids.

Fig. 42 represents a triangular prism intersecting a cylinder. The axis of the prism is parallel to V and inclined to H. Starting with the size and shape of the base, this is laid off at $a_1 b^A c^A$, and the altitude of the triangle taken and laid off at $a'' c''$ in elevation, making right angles with the inclination of the axis to H. The plan of the prism is then constructed. To find the intersection of the two solids, lines are drawn on the surface of the prism parallel to the length and the points where these lines and the edges pierce the cylinder are obtained and joined, giving the curve.

The top edge of the prism goes into the top of the cylinder. This point will be shown in elevation, since the top of the cylinder is a plane parallel to H and perpendicular to V, and therefore projected on V as a straight line. The upper edge, then, is found to pass into the top of the cylinder at point o , o'' and o^A . The intersection of the two upper faces of the prism with the top of the cylinder will be straight lines drawn from point o and will be shown in plan. If we can find where another line of the surface $o a b 14$ pierces the upper base of the cylinder, this point joined

with o will determine the intersection of this face with the top of the cylinder. A surface may always be produced, if necessary, to find an intersection.

Edge $a b$ pierces the plane of the top of the cylinder at point

Fig. 48.

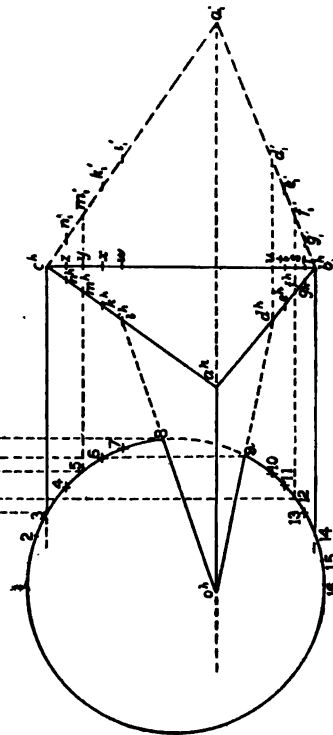
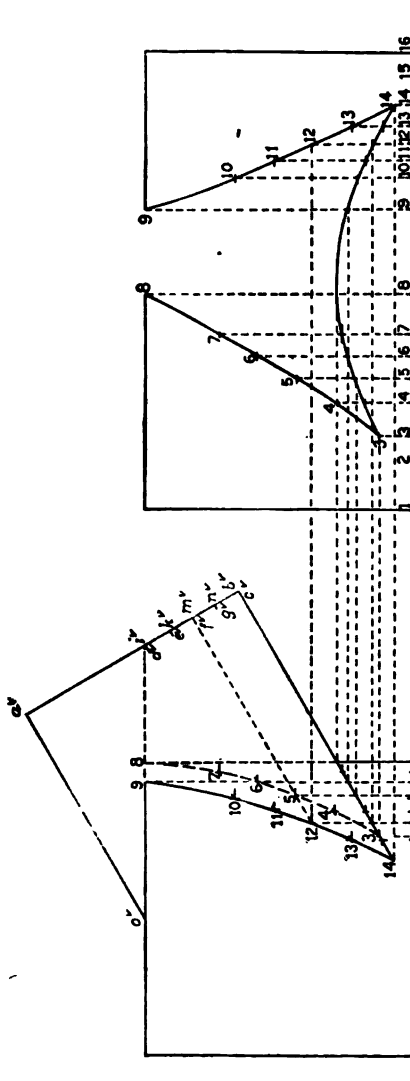


Fig. 42.

d , seen in elevation; therefore the line joining this point with o is the intersection of one upper face of the prism with the upper

base of the cylinder. The only part of this line needed, of course, is within the actual limits of the base, that is $o 9$. The intersection $o 8$ of the other top face is found by the same method. On the convex surface of the cylinder there will be three curves, one for each face of the prism. Points 8 and 9 on the upper base of the cylinder, will be where the curves for the two upper faces will begin. The point d is found on the revolved position of the base at d_1 , and $d_1 b$ is divided into the equal parts $d_1 - e_1, e_1 - f_1$, etc., which revolve back to d^h, e^h, f^h and g^h . The divisions are made equal merely for convenience in developing. The vertical projections of d, e , etc., are found on the vertical projection of $a b$, directly above d^h, e^h , etc., or may be found by taking from the revolved position of the base, the perpendiculars from d_1, e_1 , etc., to $c^h b^h$ and laying them off in elevation from b^v along $b^v a^v$. Lines such as $f 12, m 5$, etc., parallel to $a o$ are drawn in plan and elevation. Points $i^h k^h m^h n^h$ are taken directly behind $d^h e^h f^h g^h$ hence their vertical projections coincide. Points $n_1 m_1 k_1$ and i_1 are formed by projecting across from $n^h m^h k^h$ and i^h .

The convex surface of the cylinder is perpendicular to H , so the points where the lines on the prism pierce it will be projected on plan as the points where these lines cross the circle, 14, 13, 12, 11.....3. The vertical projections of these points are found on the corresponding lines in elevation, and the curves drawn through. The curve 3, 4....8 must be dotted, as it is on the back of the cylinder. The under face of the prism, which ends with the line $b c$, is perpendicular to the vertical plane, so the curve of intersection will be projected on V as a straight line. Point 14 is one end of this curve. 3 the other end, and the curve is projected in elevation as the straight line from 14 to the point where the lower edge of the prism crosses the contour element of the cylinder.

Fig. 43 gives the development of the right-hand half of the cylinder, beginning with number 1. As previously explained, the distance between the elements is shown in the plan, as 1—2, 2—3, 3—4 and so on. These spaces are laid off in the development along a straight line representing the development of the base, and from these points the elements are drawn perpendicularly.

The lengths of the elements in the development from the base to the curve are exactly the same as on the elevation, as the

elevation gives the true lengths. If then the development of the base is laid off along the same straight line as the vertical projection of the base, the points in elevation may be projected across with the T-square to the corresponding elements in the development. The points on the curve cut by the under face of the prism are on the same elements as the other curves, and their vertical projections are on the under edge of the prism, hence these points are projected across for the development of the lower curve.

In Fig. 44 is given the development of the prism from the right-hand end as far as the intersection with the cylinder, begin-

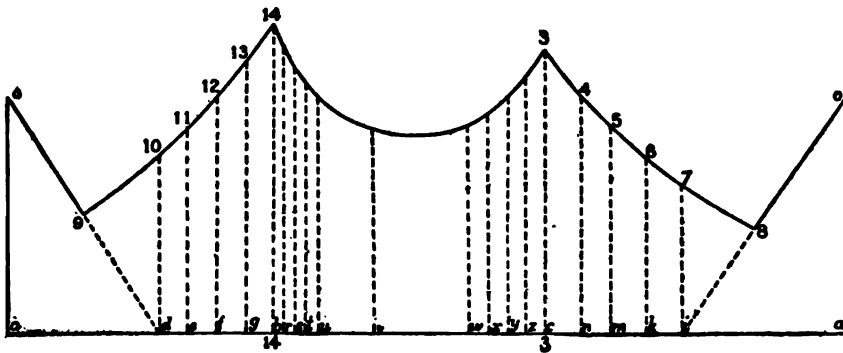


Fig. 44.

ning at the left with the top edge $a o$, the straight line $a b c a$ being the development of the base. As this must be the actual distance around the base, the length is taken from the true size of the base, $a_1 b^h c^h$. The parallel lines drawn on the surfaces of the prism must appear on the development their true distances apart, hence the distances $a_1 d_1, d_1 e_1$, etc., are made equal to $a d, d e$, etc. on the development. The actual distances between the parallel lines on the bottom face of the prism are shown along the edge of the base, $b^h c^h$. Perpendicular lines are drawn from the points of division on the development.

The position of the developed curve is found by laying off the true lengths on the perpendiculars. These true lengths (of the parallel lines) are not shown in plan, as the lines are not parallel to the horizontal plane, but are found in elevation. The length oa on the development is equal to $a^v o^v, d 10$ to $d^v 10$, and

so on for all the rest. Point 9 is found as follows; on the projections, the straight line from o to d passes through point 9, and the true distance from o to 9 is shown in plan. All that is necessary, then, is to connect o and d on the development, and lay off from o the distance o^h9 . Number 8 is found in the same way.

In Fig. 45 is shown the intersection of a triangular pyramid and pentagonal prism. The process of finding some of the points requires explanation. By inspection of the plan it may be seen that the pyramid goes into the front of the prism and comes out at the back, giving two separate intersections. We will consider first the intersection on the front on the two faces of the prism 1-5 and 5-4. The edge ao of the pyramid pierces the prism at 13. Next the edge bo pierces the edge of the prism at point 14, and these two points connected give the intersection of face $ao b$ of the pyramid with the left-hand front side of the prism. Point 15, found the same as 13, is where oc pierces the right-hand front face of the prism.

Points 14 and 15 are both on the surface $bo c$, and also on the right front side of the prism, hence the line joining these points is the intersection of the two surfaces. Now the point 15 cannot be joined directly with 13, as the two points are on different faces of the prism. The under face of the pyramid, cutting both front faces of the prism, intersects the edge 5 at some point, and this point must be on the intersection of both front faces. The principle may be stated in this way: — When a plane intersects one face of a solid, the point where this intersection crosses an edge is a point also of the intersection of the same plane with the adjoining face of the solid.

Making use of this principle, if we find the intersection of oac with face 5-4 of the prism, the point where this intersection crosses edge 5 will be a point of the intersection on face 5-1. 15 is one point on the intersection of oac with the right-hand front side of the prism. We may consider the face 4-5 of the prism extended and intersected at x by edge oa , then $x-15$ is the intersection of face oac with face 5-4 of the prism. Of course this intersection is only used as far as the edge 5, point 16, and this point is then connected with 13, giving the intersection of oac with face 5-1 of the prism, and completing the intersec-

tion on the front. This intersection is entirely visible in elevation, because all of the surfaces on which it lies are visible in elevation.

It is always true that if visible surfaces meet visible surfaces the intersections are visible, and it is this principle which deter-

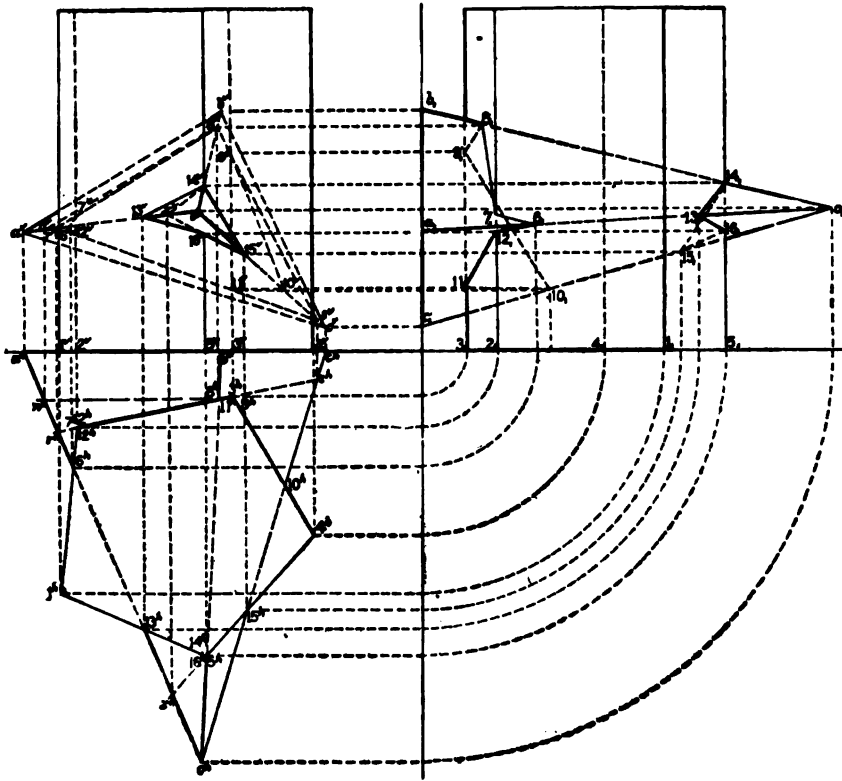


Fig. 45.

mines whether intersections are visible or not. For the intersection on the back, $a o$ comes out of the prism at 6, from which point two lines of intersection must begin, one on face $o a b$ and one on $o a c$. Edge $o b$ comes out at point 8. This point is not found in elevation by projecting from the plan, as the inclination of $o'' b''$ is such that the intersection would be very inaccurate. Instead, a plane parallel to the base is taken through point 8, on the plan, and the

intersection of this plane with the pyramid is drawn in elevation. As previously explained, this intersection is a triangle parallel to the base, one corner of which is at point n . 8^v is then found where the side of this parallel triangle crosses $o^v b^v$. Another point of the intersection on face 3 — 2 of the prism with face $o a b$ of the pyramid is where $o a$ cuts face 3 — 2 extended, at point r . This last point is connected with 8, giving point 7 on the edge 2 of the prism, which in turn connects with 6. The intersection of $o a c$ with face 3 — 2 of the prism is obtained by extending the face 3 — 2 in both directions, and joining the points r and s where $o a$ and $o c$ pass through. This intersection, as before, is continued only to the edges of the face, giving points 12 and 11. Point 12 is then joined with 6, and 11 with 10. Points 8 and 10 cannot be connected directly, but must be united by two lines meeting at a point on edge 3 of the prism. This point, numbered 9, is found by the same method as point 8. The complete intersection on the back, which is all invisible, is the seven-sided figure 6, 7 ----- 12. As much of the pyramid as is in front of the prism, and to the left and right, is shown full in elevation. It is seen by the plan that nothing is directly in front of either edge number 1 or 4, hence these edges are visible throughout in elevation. Edge 5 would be visible in elevation if the pyramid were removed, so it is made full except between 14 and 15, where it is evidently inside the pyramid.

The figure at the right is a side or profile view of the two solids, obtained by revolving as previously explained. The points in the second elevation on the edges of the prism are found by projecting directly across from the points on the first elevation. Other points such as those on $a_1 o_1$ are projected onto the profile plane from the plan, and swung around and projected up to meet $a_1 o_1$. In shading lines of intersection, a dark surface intersecting a light one gives a shade line. The line 16 — 13, being the intersection of the light face of the prism 1 — 5 with the dark face of the pyramid $o a c$, is made a shade line.

The shade lines on the side view are the same as if the solids were actually turned into that position, and a plan drawn. The same faces of the pyramid are light and dark as before.

It is sufficiently accurate to consider that surfaces of which the

light or dark condition may be determined by using the 45° triangle on the elevation will remain in the same state in the side view. These surfaces are those perpendicular to V or nearly so.

CONSTRUCTION OF THE SCREW THREAD.

In machine construction the screw holds an important place as one of the devices for transmitting and changing motion, and also as a means of fastening. The screw thread is a curve called the *helix*. The helix may be defined as the curve traversed by a point moving uniformly around on the surface of a circular cylinder and having at the same time a uniform motion along the length of the cylinder. That is, if a point moves around one-eighth of the circumference of a cylinder and at the same time one-quarter of an inch parallel to the axis, and in the next eighth of a revolution another quarter inch along the axis a helical curve is produced.

The distance measured anywhere parallel to the axis between two consecutive turns of the curve is called the pitch of the curve. In Fig. 46, for the helix shown $w = 2$, $x = 3$, or any distance measured in like manner is the pitch of the curve.

To construct the curve, divide the circumference of the cylinder in plan into some number of equal parts, in this case twelve, and lay off on an element of the cylinder a distance above the base equal to the pitch of the curve. This length is then divided into as many equal spaces as there are divisions of the base, 0, 1, 2, 3, etc. Now when a point has moved one-twelfth of the circumference, as from 0 to 1, it has moved also one-twelfth of the pitch, or to the height of division number 1 on the elevation. Hence by projecting up from 1 on the plan to this height, point 1 on the curve is obtained. The other points to 12 are found in the same way, giving one complete turn to the curve. The next turn may be found by laying off the length of the pitch along the elements of the cylinder from the points just found.

On the actual screw, after the diameter at the root of the thread is determined, the root helix is found in the same way. At the right is shown the development of part of the cylinder, the helix appearing as a straight line. This peculiarity of the helix furnishes an easy method of determining its length, starting

from any given point. Thus the length of the curve from 0 to 8 is equal to the hypotenuse of a right triangle having for a base the length of the arc 0-1---8, and for the other side the height of point 8 above the base.

WORKING DRAWINGS.

A drawing made and dimensioned in such a way that it may be given to the machinist, or pattern maker and worked from is a working drawing. A drawing intended for such service should have given all the dimensions and measurements necessary for

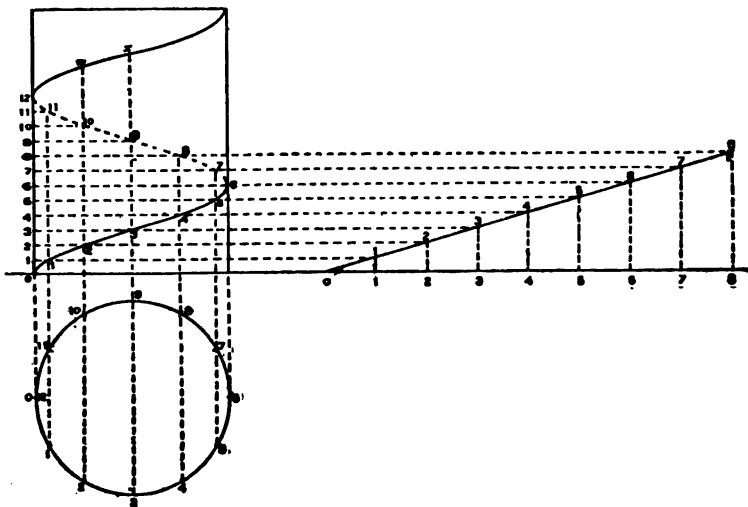


Fig. 46.

the actual construction. Certain conventionalities are observed in regard to center lines, dimension lines, and the manner of putting on the dimensions.

The center line of a piece, or of a series of holes, is made a long and short dash, as shown in Fig. 47. To give the distance between two lines, as between the top and bottom edges of the rectangular block at the left, a dash line is drawn between the edges, the distance put in a space left for that purpose, and small arrow heads just touching the two given edges. Feet are indicated by a short dash placed at the upper right of the number,

and inches by two such dashes, thus : two feet, 2'; three inches, 3".

If feet and inches are expressed together, a horizontal dash should separate them, as 6'—3½". This is important, as otherwise blunders are likely to occur in reading the dimensions. Various practices are in use as to how large a dimension should be given in inches alone. Some give anything above one foot in feet and inches; others, anything up to two feet in inches. It is, however, largely optional.

Dimension figures should be made neatly and very plainly, and should never read from more than two sides of the drawing,

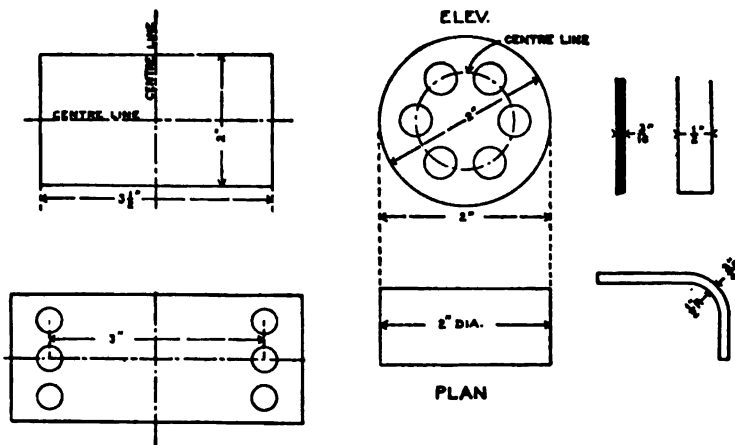


Fig. 47.

the bottom and the right hand. If the space between two edges is too small to admit both the figure and the arrow heads, the latter may be placed outside, as shown in the two figures at the right. If the space is too small for either the arrow heads or figure, both may be placed outside, as shown above.

In dimensioning a circle give the diameter, if possible. When the dimension of a round rod, or shaft is put on the view which does not show the circle, D or Dia., for diameter, should be placed after the figure. Where only an arc of a circle is given, the radius is shown in the manner indicated at the right, followed by the letter R for radius.

If a series of holes, as bolt holes, have their centers equally spaced on a circle, give the diameter of this circle. Where it is

obvious that holes are spaced equally on either side of a center line, give the distance between centers of holes.

Never place so many dimensions on any view of a piece that the drawing is confused and made difficult to understand. This may usually be avoided by distributing the measurements among the different views of the object, as the same measurement need not be given in more than one place.

If for any reason there is not room within the projection of a piece to give its dimension, extension lines may be used, that is, the edges of the piece between which the distance is required may be extended as fine dotted lines, and the dimension placed between these, as shown in the upper left-hand figure.

In a working drawing, as many views of the object should be

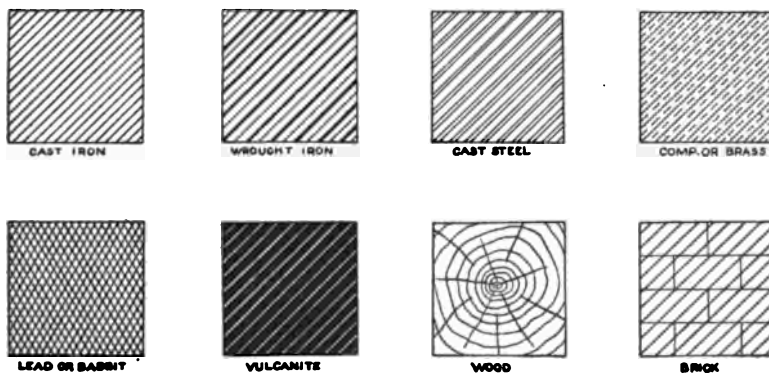


Fig. 48.

given as will suffice to make clear the shape and size. Very often plan and elevation are enough, sometimes an end or side view is required, and sometimes a bottom view or one or more sections. The ground line is almost always omitted in machine drawing, as there is little difficulty in working without one.

For use in the shop, the white paper on which the drawing is made would be unsuited. What is done is to place over the drawing a sheet of semi-transparent material, called tracing cloth, and trace the drawing with ink. This tracing is then placed over a sheet of paper, chemically treated, exposed to the sun, the under sheet washed and dried, on which will be an exact copy of the tracing. This copy is called a blue print. The blue print is then

used in the shop to work from. The method of making tracings and blue prints will be explained more fully later.

When different materials are sectioned, it is common to distinguish between them by drawing on the surface cut a series of lines. Different arrangements of these section lines denote the various substances, as lead, steel, brass, etc. This method of showing the substance sectioned is called cross-hatching.

In Fig. 48 are shown blocks of cross-hatching representing the various materials most commonly met with in machine work, according to the standard in this country.

In dimensioning a bolt, as shown in Fig. 49, one view only is often all that is required. In this case, after the breadth of the head, should be placed Dia. Sq. or Hex. to indicate the shape of the head. The length of the shank should be given, the length of either the threaded or the unthreaded part, and also the number of threads per inch. The cut shows the conventional method of representing threads on small bolts.

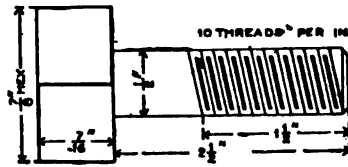


Fig. 49.

PLATES.

PLATE IX.

The plates of Mechanical Drawing III should be laid out the same size as the plates in Parts I and II. The center lines and border lines should also be drawn as described.

First draw two ground lines across the sheet, 3 inches below the upper border line and 3 inches above the lower border line. The first problem on each ground line is to be placed 1 inch from the left border line and spaces of about 1 inch should be left between the figures.

Isolated points are indicated by a small cross x, and projections of lines are to be drawn full unless invisible. All construction lines should be fine dotted lines. Given and required lines should be drawn full.

Problems on upper ground line;

PROBLEM 1. Locate both projections of a point on the horizontal plane 1 inch from the vertical plane.

PROBLEM 2. Draw the projections of a line 2 inches long which is parallel to the vertical plane and makes an angle of 45 degrees with the horizontal and slants upward to the right.

The line should be 1 inch from the vertical plane and the lower end $\frac{1}{2}$ inch above the horizontal.

PROBLEM 3. Draw the projections of a line $1\frac{1}{2}$ inches long, which is parallel to both planes 1 inch above the horizontal and $\frac{3}{4}$ inch from the vertical.

PROBLEM 4. Draw the plan and elevation of a line 2 inches long which is parallel to H and makes an angle of 30 degrees with V. Let the right-hand end of the line be the end nearer V, $\frac{1}{2}$ inch from V. The line to be 1 inch above H.

PROBLEM 5. Draw the plan and elevation of a line $1\frac{1}{2}$ inches long which is perpendicular to the horizontal plane and 1 inch from the vertical. The lower end of line is $\frac{1}{2}$ inch above H.

PROBLEM 6. Draw the projections of a line 1 inch long which is perpendicular to the vertical plane and $1\frac{1}{2}$ inch above the horizontal. The end of the line nearer V, or the back end, is $\frac{1}{2}$ inch from V.

PROBLEM 7. Draw two projections which shall represent a line oblique to both planes.

NOTE: Leave 1 inch between this figure and the right-hand border line.

Problems on lower ground line.

PROBLEM 8. Draw the projections of two parallel lines each $1\frac{1}{2}$ inches long. The lines are to be parallel to the vertical plane and make angles of 60 degrees with the horizontal. The lower end of each line is $\frac{1}{4}$ inch above H. The right-hand end of the right-hand line is to be $2\frac{3}{4}$ inches from the left-hand margin.

PROBLEM 9. Draw the projections of two parallel lines each 2 inches long. Both lines to be parallel to the horizontal and make an angle of 30 degrees with the vertical. The lower line to be $\frac{3}{4}$ inch above H and one end of one line to be against V.

PROBLEM 10. Draw the projections of two intersecting lines. One 2 inches long to be parallel to both planes 1 inch

above H and $\frac{3}{4}$ inch from the vertical, and the other to be oblique to both planes and of any desired length.

PROBLEM 11. Draw plan and elevation of a prism 1 inch square and $1\frac{1}{2}$ inches long. The prism to have one side on the horizontal plane and the long edges perpendicular to V. The back end of the prism is $\frac{1}{4}$ inch from the vertical plane.

PROBLEM 12. Draw plan and elevation of a prism the same size as given above, but with the long edges parallel to both planes, the lower face of prism parallel to H and $\frac{1}{4}$ inch above it. The back face to be $\frac{1}{4}$ inch from V.

PLATE X.

The ground line is to be in the middle of the sheet, and the location and dimensions of the figures are to be as given. The first figure shows a rectangular block with a rectangular hole cut through from front to back. The other two figures represent the same block in different positions. The second figure is the end or profile projection of the block. The same face is on H in all three positions. Be careful not to omit the shade lines, and try to see why each one is put on.

PLATE XI.

Three ground lines are to be used on this plate, two at the left, $4\frac{1}{2}$ " long and 3" from top and bottom margin lines, and one at the right, half way between the top and bottom margins, $9\frac{1}{2}$ " long.

The figures 1, 2, 3 and 4 are examples for finding the true lengths of the lines. Begin No. 1 $\frac{3}{4}$ " from the border, the vertical projection $1\frac{3}{4}$ " long, one end on the ground line, and inclined at 30° . The horizontal projection has one end $\frac{1}{2}$ " from V and the other $1\frac{1}{2}$ " from V. Find the true length of the line by completing the construction commenced by swinging the arc, as shown in the figure.

Locate the left-hand end of No. 2 3" from the border, 1" above H and $\frac{5}{8}$ " from V. Extend the vertical projection to the ground line at an angle of 45° , and make the horizontal projection at 30° . Complete the construction for true length as commenced in the figure.

In figures 3 and 4 the true lengths are to be found by completing the revolutions indicated. The left-hand end of Fig. 3 is $\frac{3}{4}$ " from the margin, $1\frac{1}{2}$ " from V and $1\frac{3}{8}$ " above H. The horizontal projection makes an angle of 60° and extends to the ground line, and the vertical projection is inclined at 45° .

The fourth figure is 3" from the border and represents a line in a profile plane connecting points *a* and *b*. *a* is $1\frac{1}{4}$ " above H and $\frac{3}{4}$ " from V, and *b* is $\frac{1}{4}$ " above H and $1\frac{1}{2}$ " from V.

The figures for the middle ground line represent a pentagonal pyramid in three positions. The first position is the pyramid with the axis vertical and base $\frac{5}{8}$ " above the horizontal. The height of pyramid is $2\frac{1}{2}$ " and the diameter of the circle circumscribed about the base is $2\frac{1}{2}$ ". The center of the circle is 6" from the left margin and $1\frac{3}{4}$ " from V. Spaces between figures to be $\frac{3}{4}$ ".

In the second figure the pyramid has been revolved about the right-hand corner of the base as an axis through an angle of 15° . The axis of the pyramid, shown dotted, is therefore at 75° . The method of obtaining 75° and 15° with the triangles was shown in Part I. From the way in which the pyramid has been revolved, all angles with V must remain the same as in the first position, hence the vertical projection will be the same shape and size as before. The points on the plan are found on T-square lines through the corners of the first plan and directly beneath the points in elevation. In the third position the pyramid has been swung around about a vertical line through the apex as axis through 80° . The angle with the horizontal plane remains the same, consequently the plan is the same size and shape as in the second position, but at a different angle with the ground line. Heights of all points of the pyramid have not changed this time, and hence are projected across from the second elevation. Shade lines are to be put on between the light and dark surfaces as determined by the 45° triangle.

PLATE XII.

Cylinders.

First draw a ground line in the middle of the plate.

A right circular cylinder, $2\frac{1}{2}$ inches diameter, is shown in three positions. The center of the first plan is $2\frac{1}{4}$ inches from

the left border and $1\frac{1}{2}$ inches from V. The length of cylinder is $3\frac{1}{4}$ inches. For the construction of the second plan the base is divided into equal parts with the 30° and 60° triangle, locating the divisions as shown.

In the second position the cylinder is inclined at an angle of 45° with the horizontal plane. The lowest corner of the elevation is on the ground line $6\frac{1}{4}$ inches from the left border. The axis of the cylinder being still parallel to the vertical plane, the vertical projection is the same size as the first elevation. The points of division on the first plan, $1^h 2^h 3^h 4^h$, etc., are projected onto V as $1^v 2^v 3^v 4^v$, etc. These points on the elevation are then transferred with the dividers to the second elevation and elements drawn as shown. The bases of the cylinder will be projected in plan as ellipses. The upper base is found in plan by projecting $1^v, 3^v$, etc., down to meet horizontals from the points numbered the same on the first plan, and the lower base is obtained in the same way. The student should observe that the method used is identical with that on the last plate for the pyramid. In the third figure the angle which the cylinder makes with the horizontal is the same, 45° , so the plan will be the same as in the second position, except that the elements make 60° with the ground line instead of being parallel. Point 2^h is to be located $\frac{1}{2}$ inch from V and $1\frac{1}{4}$ inches from the right border. Notice that in this case the upper base is the one farthest from the vertical, so that the right-hand contour in plan corresponds with the back element in the second plan. An easy way to construct the plan is to work from the center element $1^h 2^h$, which is made the same length as in the second plan. Note the points $a b c x y z$, etc., in the second plan where the projecting lines from the elevation cross the center line, and with the dividers space these points off in the same positions on the new center line $1^h 2^h$, and through these points of division draw lines perpendicular to the center line equal in length to the same lines on plan number two. To illustrate, the distance $3^h x$ on the third plan is the same as $3^h x$ on the second, and so on. After finding the twelve points on each base in elevation by using the construction as illustrated for points 1 2 3 4, the contour elements are drawn tangent to the bases. As in the second and third figures the shade

lines cannot be determined with the 45° triangle, owing to the obliquity of position, therefore they are omitted altogether.

PLATE XIII.

Conic Sections.

First draw a ground line through the center of the plate.

The bases of all the solids of this plate are of the same size, $2\frac{1}{2}$ inches in diameter. First divide the circumference of the base into twelve equal parts, using the 60° and 30° triangle.

The first figure is a cylinder 3 inches long with its base against V. The center of base is $1\frac{1}{8}$ inches above H and $1\frac{1}{8}$ inches from the left border. The cutting plane is vertical, makes an angle 30° with V, and passes through a point on the right-hand element of the cylinder $\frac{1}{4}$ inch from the ground line. The section, which is an ellipse, is projected in elevation as the base of the cylinder. Its true size is found as in Fig. 32. A space of $\frac{1}{8}$ inch is left between the first and second figures.

The second solid is a right circular cone standing on its base, the center of which is $1\frac{1}{2}$ inches from the vertical plane. The height of cone is 3 inches. In this case the cutting plane makes an angle of 30° with the horizontal and is drawn from a point on the right-hand element $\frac{1}{4}$ inch from its lower end. The method of construction has been fully explained before. The extreme ends of the ellipse, where the plane intersects the contour elements, are projected on the plan on the horizontal center line.

Use a horizontal plane half way between the extreme ends on the elevation, and two on either side, equally spaced, as shown. For drawing the true size of the section, locate the center line $1\frac{1}{2}$ inches from the cutting plane and parallel to it.

The third figure is the same size as the second, the same distance from V, and $\frac{1}{8}$ inch from the second figure. The cutting plane here is a profile plane taken $\frac{3}{8}$ inch to the left of the axis. The section is a hyperbola, and is projected in both plan and elevation as a straight line. The points on the plan of the curve, 1, 3, etc., are found by taking a series of horizontal planes on the elevation in exactly the same way as given in Fig. 34. The distance from the highest point, 8, to the base is divided into six equal parts, and planes drawn through these divisions. The highest of

the six spaces is also divided again in the middle, and another plane drawn. This is because near the top, or vertex of the hyperbola, the curvature changes rapidly, and more points are needed to determine accurately the shape of the curve. The circles cut by these planes are found in plan as shown, and the points 1, 3, 4, etc., are points on the curve. Before drawing the circles, the planes should be numbered from 1 to 15, inclusive, beginning at the base. The points on the bottom plane, 1 and 15, are found in plan on the circumference of the base; 3 and 13, on the third plane, are found in plan where the corresponding circle cuts the section plane at 3 and 13, and the other points are determined in the same way. To represent the true size and shape of the curve, the profile plane is revolved into the vertical about its intersection with V as the axis. The points on the plan move in arcs of circles with 1 on the ground line as a center. The heights in the revolved position must be the same as in elevation, and directly above the revolved positions on the ground line. The hyperbola is obtained by drawing a smooth curve through the points found. Since the curve is symmetrical with respect to its axis, only the left-hand side is obtained by revolution, the right-hand half being found by laying of horizontal distances to the right of the revolved axis equal respectively to those on the left.

The last figure represents the projection of a right circular cone with its axis parallel to the ground line, $1\frac{1}{2}$ inches above H and $1\frac{1}{2}$ inches from V, and $2\frac{1}{2}$ inches long. The apex is $\frac{1}{2}$ inch from the right-hand border line. The section plane is perpendicular to H and parallel to the back element of the cone in plan, and is drawn from a point on the base $\frac{1}{2}$ inch from the back corner. The curve in this case must be a parabola, with the vertex at the point where the section plane cuts the front element in plan.

The method used in this problem is to draw a number of elements of the cone and find the points where these intersect the cutting plane. These points are points on the curve. This method might have been used in the second and third examples, or in any case where a plane cuts a cone. If elements are drawn on the cone in plan and the points noted where they intersect the

base, the vertical projections of these points cannot be found without some intermediate step. The base of the cone is a circle, and if it is revolved about its horizontal diameter as an axis until parallel to H, one-half of its projection on H will be as shown by the dotted semi-circle. Distances from points 1, 2, 3, etc., on the revolved base of the cone to the points where the elements meet the base are the distances of points on the circumference of the base above and below the horizontal diameter. These lengths, therefore, laid off on the elevation of the base above and below the center give the vertical projections of points 1^v, 3^v, etc. To illustrate consider the element marked $x^h y^h$ on the plan. This must represent the horizontal projection of two elements, x and y , one on the upper part of the cone, and one on the lower. The point where this element meets the base revolves to 6, 8, on the semi-circle, and the horizontal distance 6, 8 to the base laid off in elevation above and below the center gives points 6 and 8 from which to draw the vertical projections x^v and y^v of the two elements x and y . The vertical projections of the other elements are found in the same way.

Strictly, the numbers on the semi-circle from 8 to 13 inclusive, being on the lower half of the cone, should appear on the other half of the revolved base, which is omitted for the sake of simplicity. Instead of choosing elements at random on the plan, the base is divided into some number of equal parts, and the elements corresponding thus found in plan and elevation. In this case, the lower quarter of the revolved base is divided into four equal parts, and one of these parts laid off above the diameter at point 2, the space 2-1 not being equal to the others. Two points of the curve are found where the section plane crosses the projection of the base, 1^h and 13^h, whose vertical projections are found as explained at 1^v and 13^v. The elements drawn intersect the cutting plane at points projected in plan, as 2^h, 3^h, 4^h, etc., and these points projected above onto the vertical projections of the corresponding elements give points on the curve, 2^v, 3^v, 4^v, etc.

To find the true size of the section, the method of the first figure or that of the second figure might be used, but the one here given is sometimes convenient. The cutting plane in this problem is perpendicular to the horizontal plane. If we take the

intersection of this plane with the horizontal plane as an axis, and revolve the plane down until it is flat on H, any point in the plan will appear on H at a perpendicular distance from the axis of revolution equal to the height of the point as shown in elevation. That is, to find the position of any point in the curve, as 12, after the plane is laid over onto H, draw a line through 12^h perpendicular to the cutting plane, and lay off from 12^h the distance from 12^v to the ground line, giving 12, as the revolved position of the point. All other points are revolved in the same way.

PLATE XIV.

Intersections and Developments.

On this plate, the intersection of a right circular cone with a right circular cylinder is to be found. The base of the cone is 3 inches in diameter; the center of the base is $1\frac{7}{8}$ inches from the vertical plane and 3 inches from the left-hand border line. The height of the cone is $3\frac{1}{2}$ inches. The axis of the cylinder is $1\frac{1}{2}$ inches above H and $2\frac{1}{4}$ inches in front of V. The diameter of the cylinder is 2 inches and the length is $3\frac{1}{2}$ inches. The left-hand end of the cylinder is $1\frac{1}{4}$ inches from the left-hand border.

In this problem we cannot readily see in either plan or elevation where one solid passes through the other.

The method used in such cases is to take a series of planes, find the lines which any one of these cuts from the two solids, and the intersections of these lines will be points on the curve. Of course the planes should be chosen to cut either straight lines or circles from the solids. In this problem a number of horizontal planes are taken to cut *elements* from the *cylinder* and *circles* from the *cone*. In order to determine what elements the planes will intersect on the cylinder, it is necessary to revolve the end of the cylinder parallel to the vertical plane, using the back point of the base as center. The true size of the base is divided into a number of equal parts (twelve in this case); these points projected back to the plan and elevation of the base, and elements drawn on the cylinder. The horizontal planes referred to above are taken through these elements, represented on V as A, B, C, etc. The circles cut by these planes from the cone are found and lettered A, B, C, etc., on the plan. The circle A and the element A must

intersect, as they are in the same plane and their horizontal projections cross. The circle is on the surface of the cone and the element on the surface of the cylinder, hence their points of intersection, of which a is one, must be on both surfaces, that is, points on the required curve of the intersection. The curve on the right-hand half of the cone must be symmetrical with that on the left, hence only the left-hand points have been numbered or lettered. The other horizontal planes are used and the other points found as explained for plane A; elements intersecting circles of the same number or letter being points of the curve.

Before working out the actual intersection we should consider that the solids may be so placed as to give one curve, or two, and it is better to settle this question before finding the points. We cannot tell by an inspection of the figures whether the front center element of the cone Vo , intersects the cylinder or not. If both front and back elements pierced the cylinder there would be two separate curves, as every element of the cone would then pass into the cylinder on the bottom, giving one curve, and out again at the top, making another. On the other hand, if both front and back elements were entirely outside the cylinder, it would then pass through the cone, giving two distinct curves.

We can find the relation of these extreme elements of the cone to the cylinder by comparing the profile view of the cone with the end view of the cylinder, shown at the right dotted. The vertex of the cone, V , is projected on the plane of the base, and revolved, giving V_1 , and the axis is drawn vertical. The base may then be spaced off on the ground line half on either side of the axis, or the base projected over on the plan, and then revolved. The front center element is shown revolved at $V_1 o_1$ and the back center element on the left of the axis.

It is thus seen that as both elements do not pass through the cylinder, and both are not entirely outside, one solid cannot be inclosed by the other, that is, there is only one curve. The cylinder lies in on the front side of the cone. Where $V_1 o_1$ intersects the revolved base are points of the curve, when found on plan and elevation of Vo . The two contour elements of the cone in elevation as shown in the revolved position as the axis, and x'' and r'' , found by projecting across from x_1 and r_1 , are

also points of the curve. In getting the intersection of two curved solids, points on the contours are always important to find, as the direction of the curve necessarily changes more or less abruptly wherever it touches these elements. Point z is seen by the plan to be on the front of both solids, so it is visible in elevation. The curve passing through this point must then remain visible in elevation until it reaches a contour element, as at g'' , and similarly on the right-hand side. The only other visible portion of the curve is found at the top.

After leaving g'' the curve is on the back of the cylinder and does not come to the front again until a'' on the upper contour is passed. On the plan all of the curve which is on the upper half of the cylinder is visible, one half being $d^h c^h b^h a^h g^h$. At the point on a contour element where a visible curve ends, the element begins to be visible outward, that is, away from the visible part of the curve. A visible contour element of one solid cannot pass through a visible contour element of another solid. In this way as the lower element of the cylinder is visible to g'' , the contour of the cone must be invisible after it crosses this element. Place the development of the cone at the right of the plate, showing the curve of intersection. If a pattern of this shape were to be made with a hole cut having the shape of the intersection, and the pattern rolled up to form a cone, a cylinder 2 inches in diameter might be placed in the gap and have every point of the curve touch the surface. V , representing the vertex of the cone, is to be located $1\frac{7}{8}$ inches to the left, and $3\frac{1}{8}$ inches below the border lines. Element $V o$ is to be the middle of the development, and is drawn at an angle of 30° with the horizontal. The development of the base of the cone is made as previously explained. To get the development of the section curve, the developments of the circles A , B , C , etc., are drawn. The radii for these circles are the lengths taken in elevation from the points where the respective planes of the circles meet the contour of the cone to the vertex.

The point g of the curve is located by finding its distance from where the circle G crosses element $V o$, shown in plan, and laying this distance off on the development along circle G from $V o$. This distance cannot be found exactly on the plan, as

it is a distance around the arc, but is gotten approximately by dividing the arc between g^h and element $V^h o^h$ into a number of small parts, then laying off the lengths of these parts with the dividers on the circle G in the development. For convenience these parts are all made equal except the last one, which is left to come wherever it will. The back element, $V s$ is developed at $V s'$ and $V s''$, therefore points which in plan are near to $V s$ may be spaced from it instead of $V o$. This has been done for points c and b . After the points on one side of $V o$ are developed, the other side may be laid off at once with the dividers, as the halves must be symmetrical.

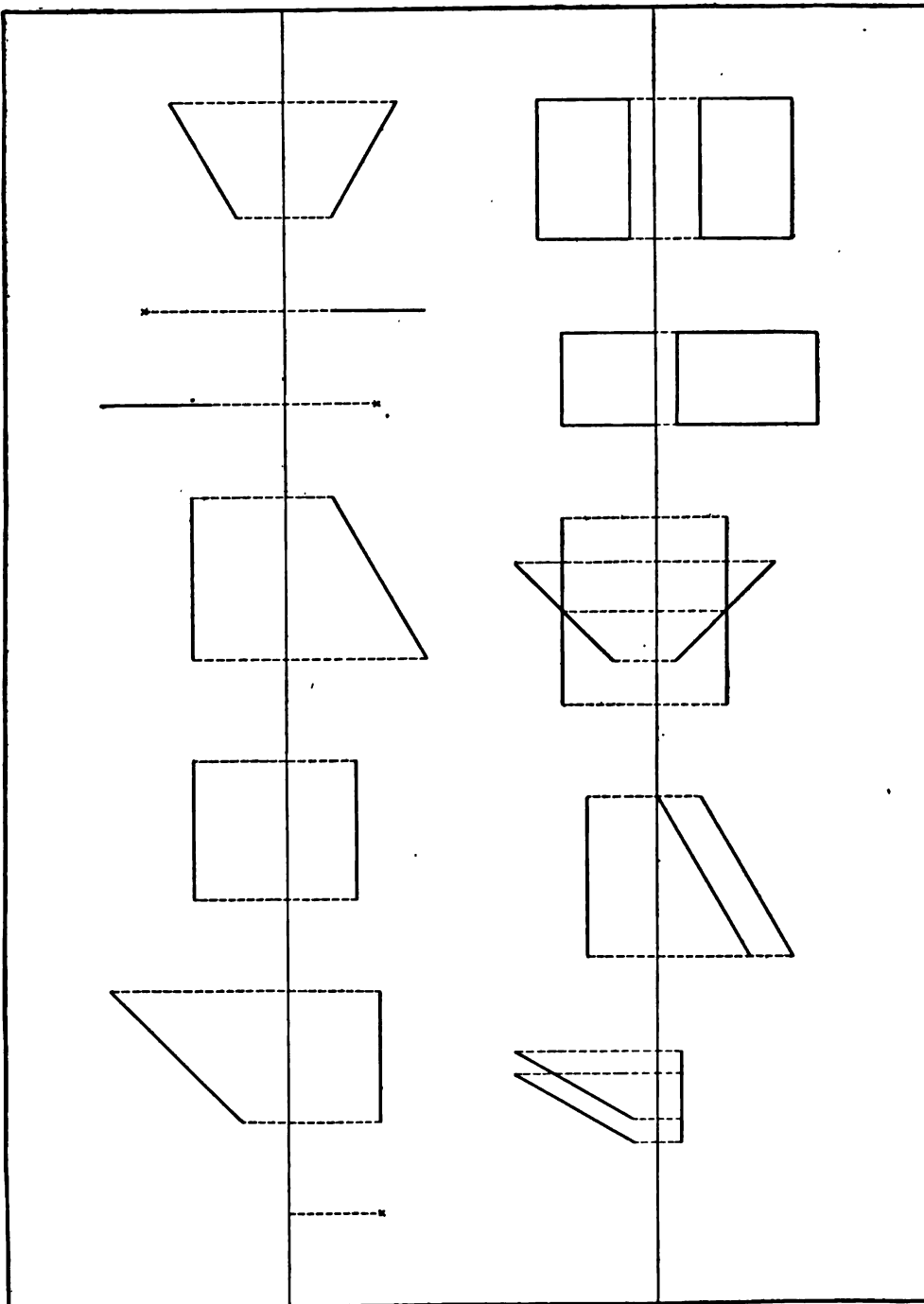
PLATE XV.

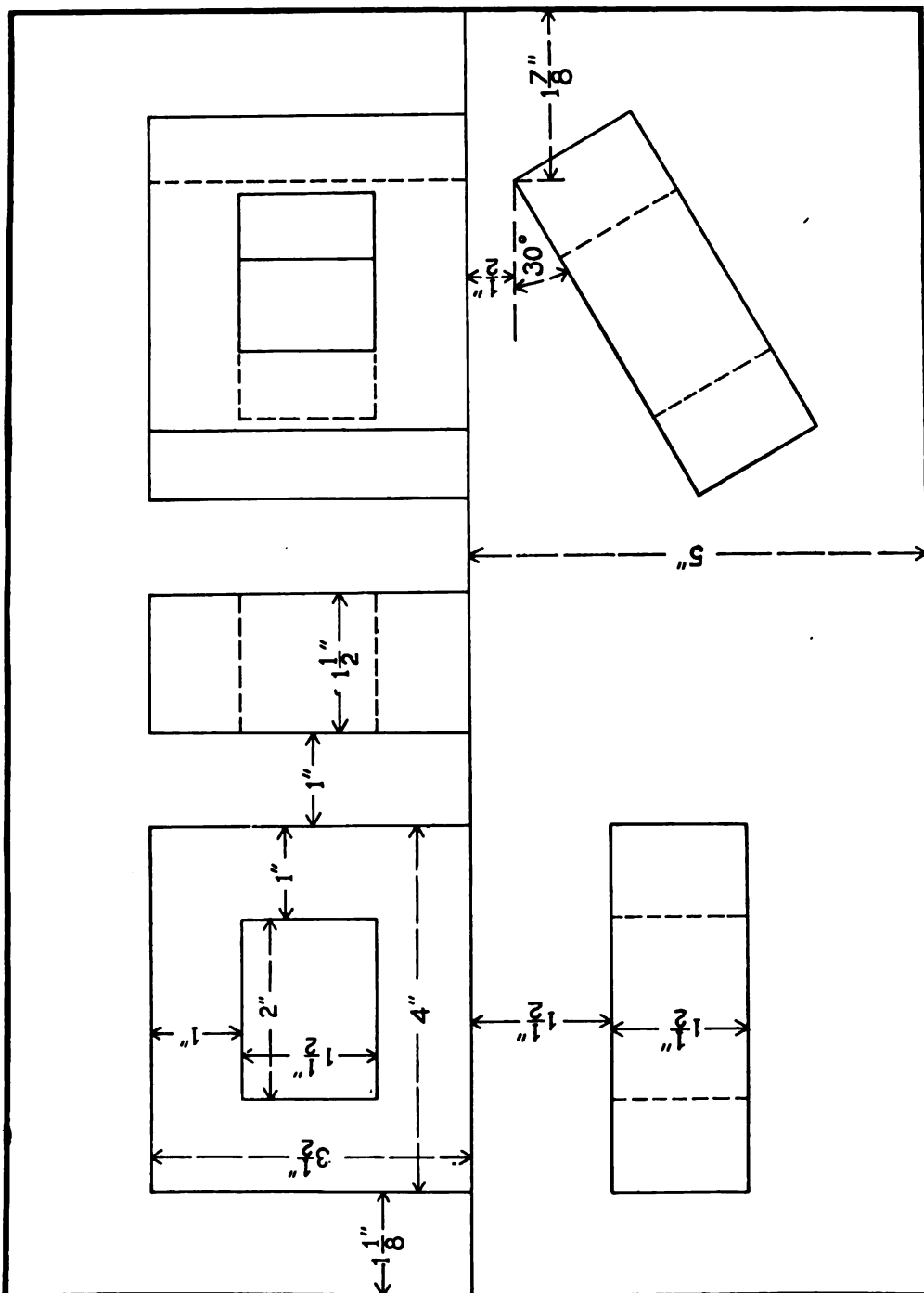
Pipe Coupling.

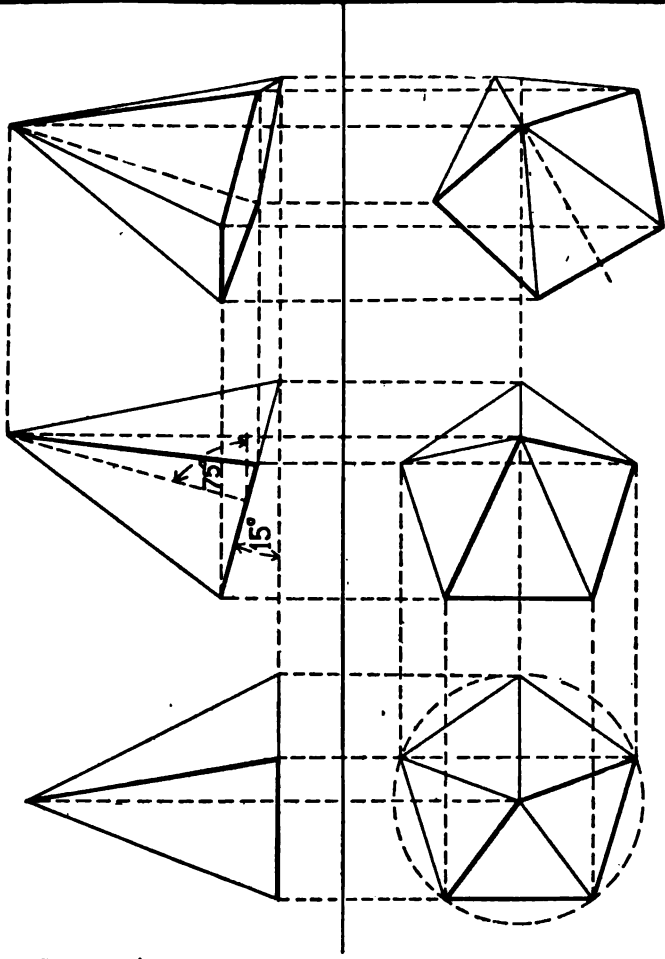
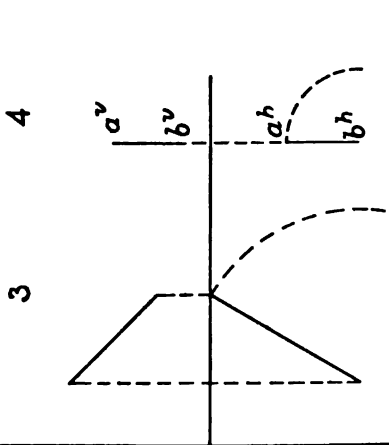
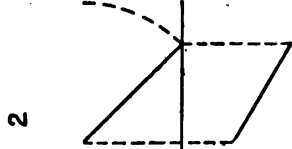
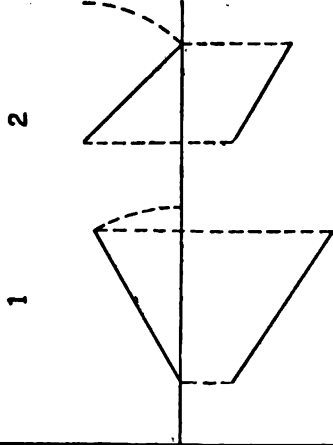
The vertical center line of the coupling is in the center of the sheet. The bottom of the elevation is to be $1\frac{1}{8}$ inches from the top margin, and the center of the plan $4\frac{1}{8}$ inches from the lower margin. This plate represents one of a pair of couplings used for connecting two lengths of pipe. The coupling is made of cast-iron, and the bore is threaded for the end of the pipe. The coupling is threaded for a right-handed thread, but as in the section on the elevation the back part of the thread is visible, it appears left-handed. When the axis of a screw is held vertically, a right-hand thread rises to the right, a left thread rises to the left. The threads are represented in the conventional manner, no particular pitch being laid off.

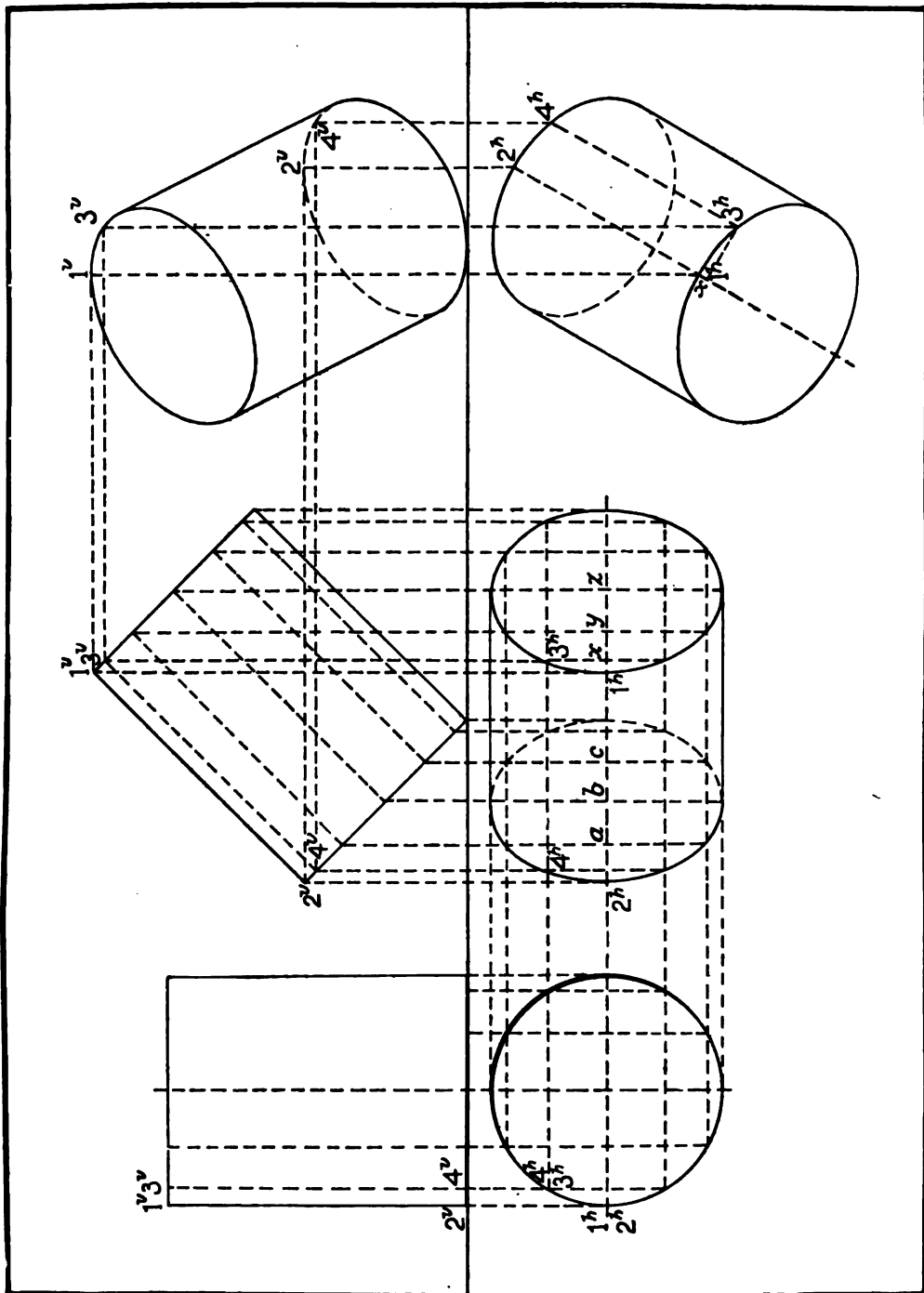
The dotted line at the left of the hole means that the hole is threaded, and is at a distance from the edge of the hole equal to the depth of the thread, $\frac{3}{8}$ inch. The elevation is made half section, that is for the right-hand half, a vertical plane has been cut through the center of the coupling, and the front half removed. Wherever the solid metal is cut by the plane, the surface is crosshatched, but where the cutting plane passes through a hole or opening, the crosshatching is omitted. To show on the plan that the bore in the coupling is threaded, or tapped, two circles are drawn, a dotted one equal to the largest diameter of the thread, and a solid one equal to the inside or root diameter. The bolt holes for fastening the two parts of the

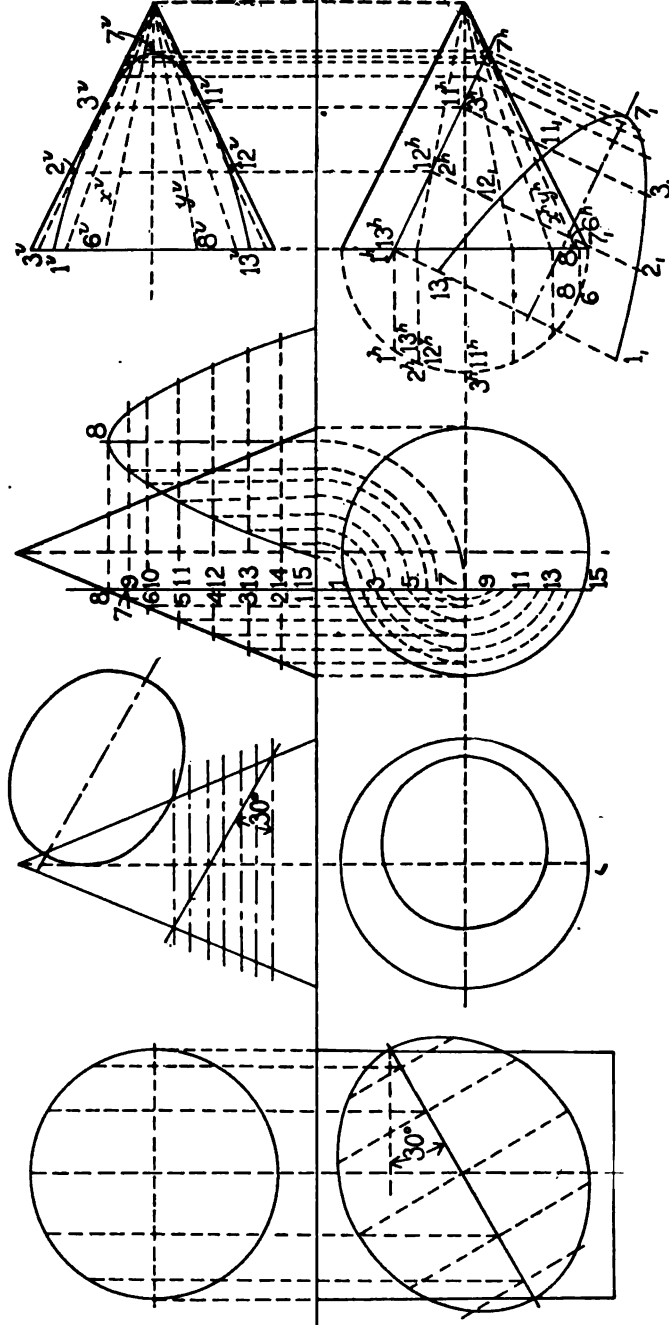
coupling together are four in number and $\frac{3}{4}$ inch in diameter. For the sake of strength the coupling has a boss or hub $3\frac{1}{2}$ inches in diameter. The title of the plate, Pipe Coupling, is placed at the right in the center of the space. The size of the letters may be the same as those used for the student's name and may be either vertical or inclined Gothic capitals.

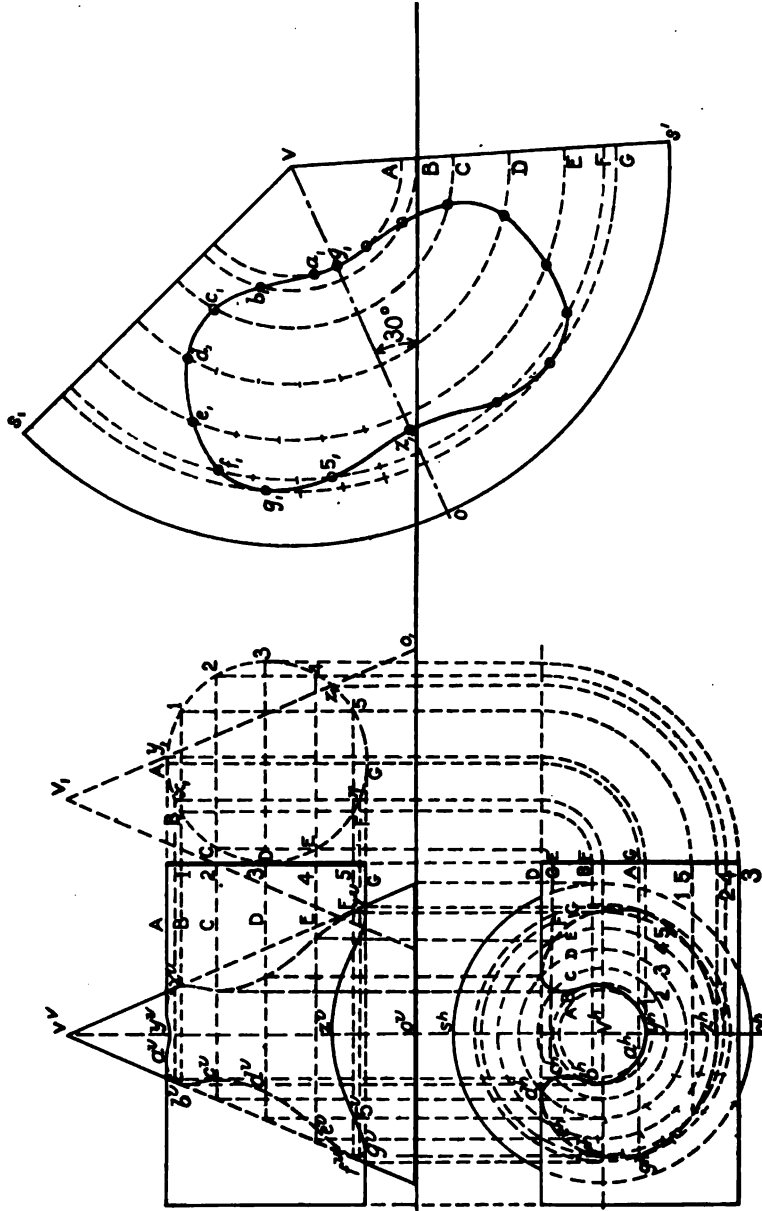


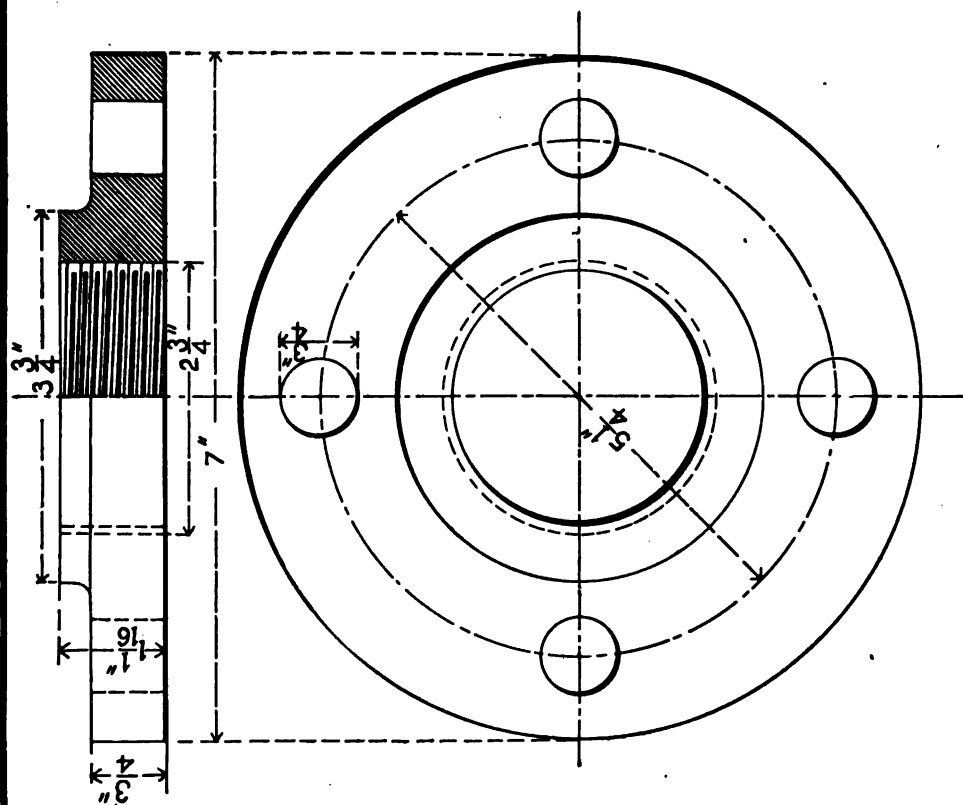












SECTION 4.

MECHANICAL DRAWING.

PART IV.

PROJECTIONS.

In the method of drawing discussed in Part III, an object is represented by two or more projections. Another system, called **isometrical drawing**, is also used to show in one view the three dimensions of an object, length (or height), breadth and thickness. An isometrical drawing of an object, as a cube, is called for short the *isometric of the cube*.

Fig. 1 shows the isometric of a cube, in which the top and two sides are visible. All of the edges are shown in their true length, hence all the surfaces appear of the same size. In the figure the edges of the base are inclined at 30° with a T square line, but this is not always the case. For rectangular objects, such as prisms, cubes, etc., the base edges are at 30° , only when the prism or cube is supposed to be in the simplest possible position. The cube in Fig. 1 is supposed to be in the position indicated by plan and elevation in Fig. 2; standing on its base with two faces parallel to the vertical plane.

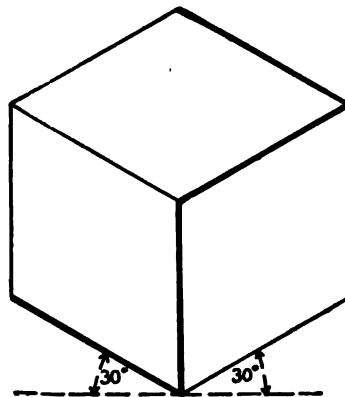


Fig. 1.

If the isometric of the cube in the position of Fig. 3 were required, it could not be drawn with the base edges at 30° , neither would these edges appear in their true lengths. It follows, then, that in isometrical drawing, true lengths appear only as 30° lines, or vertical lines. Edges or lines which in actual projection are either parallel to the ground line or perpendicular to V are drawn in isometric as 30° lines, full length, and those which are actually vertical are made vertical in isometric, also full length.

In Fig. 1, lines such as the front vertical edge of the cube and the two base edges are called the three **isometric axes**. The isometric of objects in oblique positions can only be constructed by reference to their projections, by methods which will be explained later.

Small rectangular objects are more satisfactorily represented in isometric drawing than large curved ones. In woodwork, mortises and joints and various parts of framing are well shown in isometric. This system is used also to give a kind of bird's eye view of mills or factories. It is also useful in making

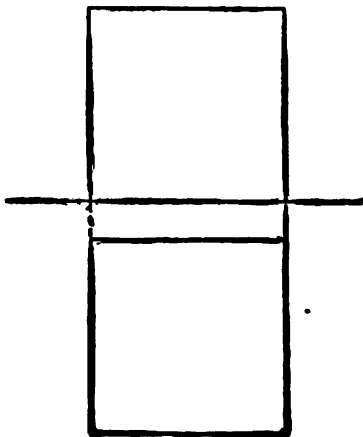


Fig. 2.

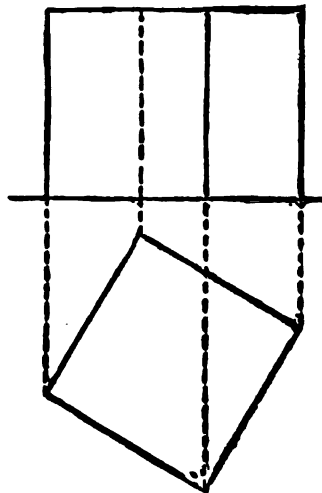


Fig. 3.

sketches of small rectangular pieces of machinery, where it is desirable to give shape and dimension in one view.

In Fig. 4 is shown the manner in which the isometric projection of a cube may be derived. Starting from the simple position of the left-hand figure, the cube is swung around to the second position, where the diagonal is parallel to the vertical plane and slopes downward to the left. In the third view the cube has been revolved about an axis through the lower right-hand corner until the diagonal is parallel to the horizontal plane, becoming thus parallel to both planes. The plan is found by the principles of projection from the elevation and the preceding plan. The

cube is next revolved about a vertical axis, (the plan remaining the same size) until the diagonal is perpendicular to the vertical plane, the end 6 being nearer V. From this new plan the elevation is constructed, giving the isometrical projection of the cube. In this last position, as one diagonal is perpendicular to V, it follows that all the faces of the cube make equal angles with V, hence are projected on V as equal parallelograms. For the same reason all edges of the cube are projected in elevation in equal lengths. These lengths, however, are evidently less than the true lengths, as the edges are not parallel to the plane; and herein

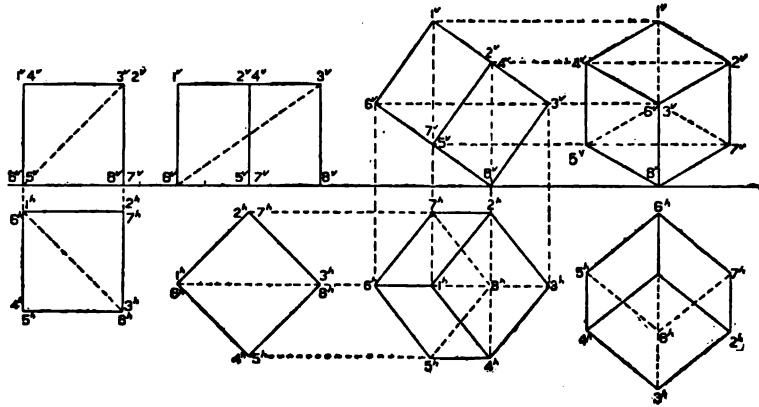


Fig. 4.

lies the distinction between an isometrical projection and an isometrical drawing, or isometric.

In the isometrical drawing the shortening of length is disregarded, and the edges made full length. This leaves the relative proportions the same, is much simpler, and is always used in practice. In isometric drawing the direction of the ray of light is parallel to that diagonal of a cube which runs from the upper left corner to the lower right, as 4^v-7^v in the last elevation of Fig. 4. This diagonal is at 30° , hence in isometrical drawing the direction of the light is at 30° downward to the right. From this it follows that the top and two left-hand faces of the cube are light, the others dark. This explains the shade lines of Fig. 1.

In Fig. 4 the top end of the diagonal which is parallel to the ray of light in the first position is marked 4, and traced through to the last or isometrical projection, 4°. It will be seen that face 3° 4° 5° 8° of the isometric projection is the front face of the cube in the first view, hence we may consider the left front face of the isometric cube as the front. This is not absolutely necessary, but by so doing the isometric shade edges are exactly the same as on the original projection.

Fig. 5 shows a cube with circles inscribed in the top and two side faces. The isometric of a circle is an ellipse, the exact construction of which would necessitate finding a number of points;

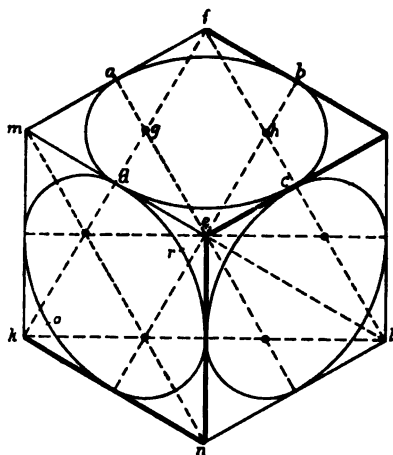


Fig. 5.

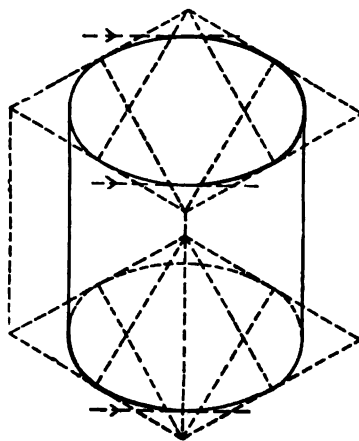


Fig. 6.

for this reason an approximate construction by arcs of circles is often made. In the method of Fig. 5, four centers are used. Considering the upper face of the cube, lines are drawn from the obtuse angles f and e , to the centers of the opposite sides.

The intersections of these lines give points g and h , which serve as centers for the ends of the ellipse. With center g and radius $g a$, the arc $a d$ is drawn, and with f as center and radius $f d$, arc $d c$ is described, and the ellipse finished by using centers h and e . This construction is applied to all three faces.

Fig. 6 is the isometric of a cylinder standing on its base. Notice that the shade line on the top begins and ends where T .

square lines would be tangent to the curve, and similarly the part shown on the base. The explanation of the shade is very similar to that in projections. Given in projections a cylinder standing on its base, the plan is a circle, and the shade line is determined by applying the 45° triangle tangent to the circle. This is done because the 45° line is the projection of the ray of light on the plane of the base.

In Fig. 5, the diagonal ml may represent the ray of light, and its projection on the base is seen to be kl , the diagonal of the base, a T-square line. Hence for the cylinder of Fig. 6, apply tangent to the base and also to the top a line parallel to the projection of the ray of light on these planes, that is, a T-square line, and this will mark the beginning and ending of the shade line.

In Fig. 5 the projection of the ray of light diagonal ml , on the right-hand face is el , a 30° line, hence in Fig. 7, where the base is similarly placed, apply the 30° triangle tangent as indicated, determining the shade line of the base. If the ellipse on the left-hand face of the cube were the base of a cone or cylinder extending backward to the right, the same principle would be used.

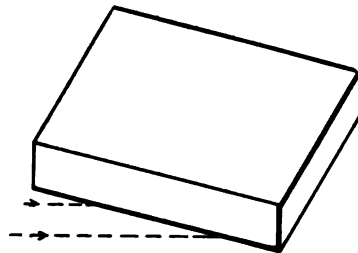


Fig. 8.

would be used tangent to the base in this last supposed case, giving the ends of the shade line at points o and r . Figs. 8, 9 and 10 illustrate the same idea with respect to prisms, the direction of the projection of the ray of light on the plane of the base being used in each case to determine the light and dark faces and hence the shade lines.

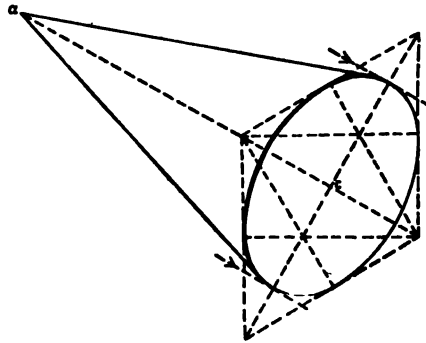


Fig. 7.

In Fig. 8 a prism is represented standing on its base, so that the projection of the cube diagonal on the base, (that is, a T-square line) is used to determine the light and dark faces as shown.

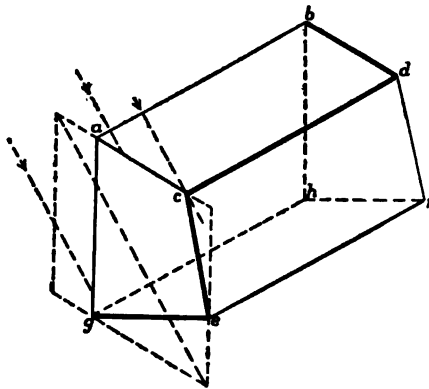


Fig. 9.

The prism in Fig. 9 has for its base a trapezium. The projection of the ray of light on this end is parallel to the diagonal of the face, hence the 60° triangle applied parallel to this diagonal shows that faces $a c d b$ and $a g h b$ are light, $c e f d$ and $g e f h$ dark, hence the shade lines as shown.

The application in Fig.

10 is the same, the only difference

being in the position of the prism, and the consequent difference in the direction of the diagonal.

Fig. 11 represents a block with smaller blocks projecting from three faces.

Fig. 12 shows a framework of three pieces, two at right angles and a slanting brace.

The horizontal piece is mortised into the upright as indicated by the dotted lines. In Fig. 13 the isometric outline of a house is represented, showing a dormer window and a partial hip roof; $a b$ is a hip rafter, $c d$ a valley. Let the pitch of the main roof be shown at B, and let c be the middle point of the top of the end wall

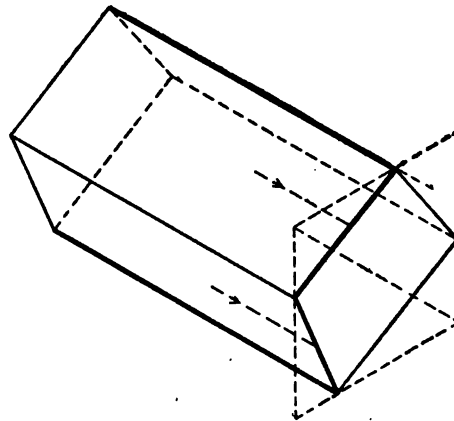


Fig. 10.

of the house. Then by measuring vertically up a distance $c l$ equal to the vertical height shown at B, a point on the line of the ridge will be found at l . Line $l i$ is equal to $b h$, and $i h$ is then drawn.

Let the pitch of the end roof be given at A. This shows that the peak of the roof or the end a of the ridge, will be back from the end

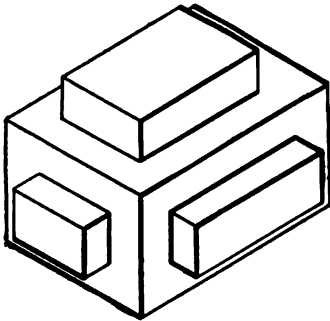


Fig. 11.

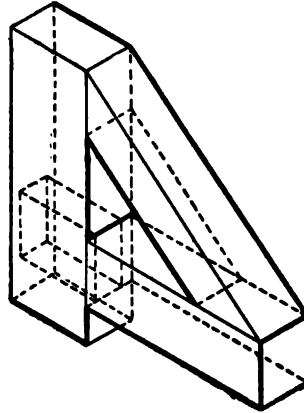


Fig. 12

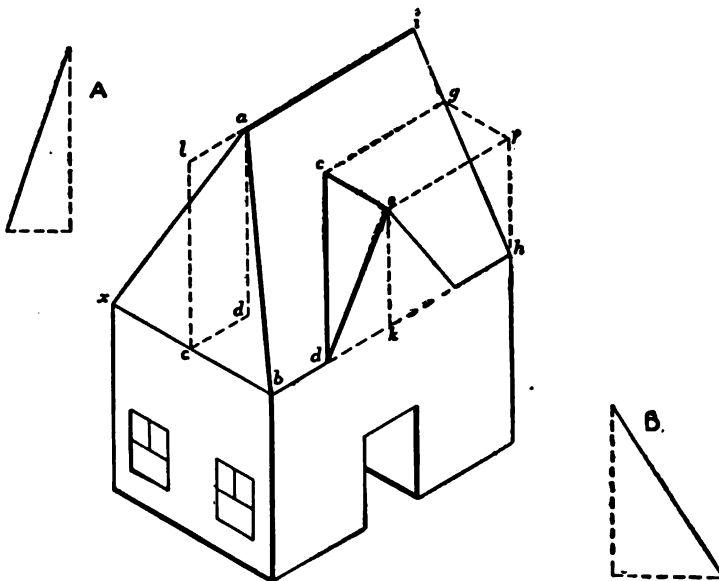


Fig. 13.

wall a distance equal to the base of the triangle at A. Hence lay off from l this distance, giving point a and join a with b and x . The height ke of the ridge of the dormer roof is known and we must

find where this ridge will meet the main roof. The ridge must be a 30° line as it runs in parallel to the end wall of the house and to the ground. Draw from e a line parallel to $b h$ to meet a vertical through h at f . This point is in the vertical plane of the end wall of the house, hence in the plane of $i h$. If now a 30° line be drawn from f parallel to $x b$, it will meet the roof of the house at

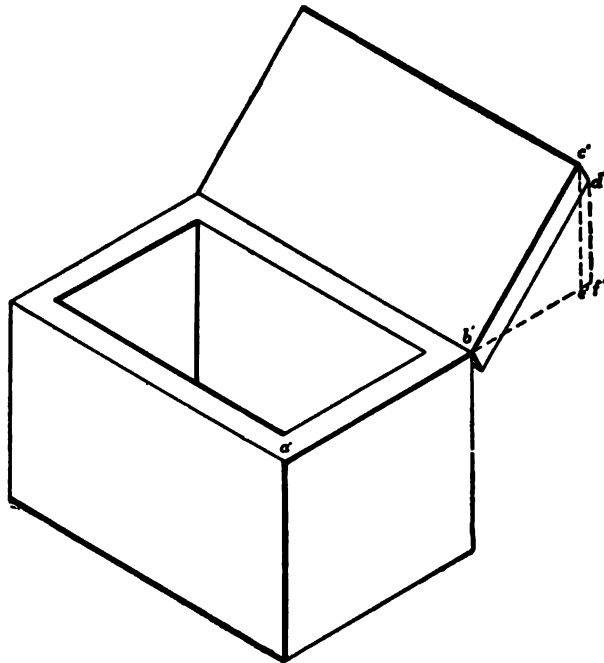


Fig. 14.

g . The dormer ridge and $f g$ are in the same horizontal plane, hence will meet the roof at the same distance below the ridge $a i$. Therefore draw the 30° line $g c$, and connect c with d .

In Fig. 14 a box is shown with the cover opened through 150° . The right-hand edge of the bottom shows the width, the left-hand edge the length, and the vertical edge the height. The short edges of the cover are not isometric lines, hence are not shown in their true lengths, neither is the angle through which the cover is opened represented in its actual size.

The corners of the cover must then be determined by co-ordinates from an end view of the box and cover. As the end of

the cover is in the same plane as the end of the box, the simple end view as shown in Fig. 15, will be sufficient. Extend the top

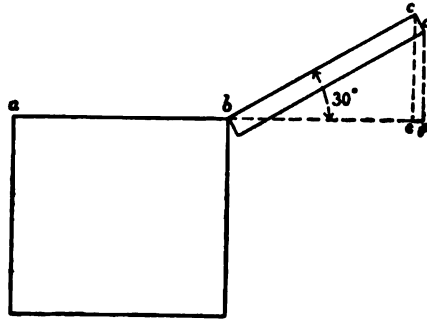


Fig. 15.

of the box to the right, and from c and d let fall perpendiculars on ab produced, giving points e and f . The point c may be located by means of the two distances or co-ordinates be and ec , and these distances will appear in their true lengths in the isometric view. Hence produce ab' to e' and f' and from these points draw verticals $e'c'$ and $f'd'$; make $b'e'$ equal to be , $e'c'$ equal to ec , and similarly for d' . Draw the lower edge parallel to $c'b'$ and equal in length and connect with b' .

It will be seen that in isometric drawing parallel lines always appear parallel. It is also true that lines divided proportionally maintain this same relation in isometric drawing.

Fig. 16 shows a block or prism with a semi-circular top. The approximate construction is used. The centers for the back face are found by projecting the front face centers back 30° equal to the thickness of the prism, as shown at a .

The plan and elevation of an oblique pentagonal pyramid is shown in Fig. 17.

It is evident that none of the edges of the pyramid can be drawn in isometric as either vertical or 30° lines, hence a system of co-

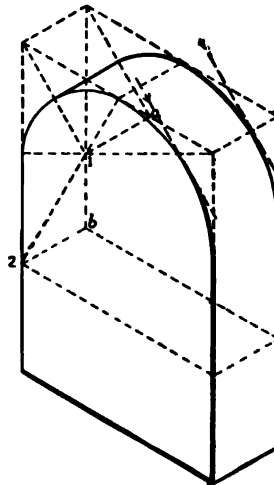


Fig. 16.

ordinates must be used as shown in Fig. 14. This problem illustrates the most general case, and to locate some of the points three co-ordinates must be used, two at 30° and one vertical.

Circumscribe a rectangle about the plan of the pyramid, which shall have its sides respectively parallel and perpendicular to the ground line. This rectangle is on H, and its vertical projection is in the ground line.

The isometric of this rectangle can be drawn at once with 30° lines, as shown in Fig. 18, o being the same point in both

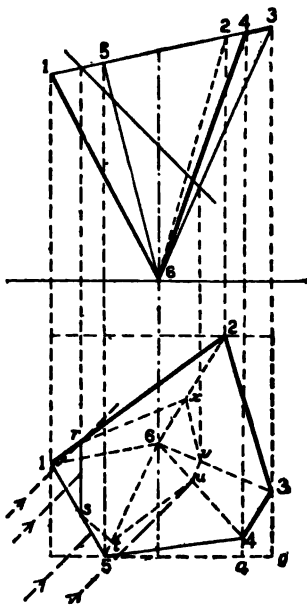


Fig. 17.

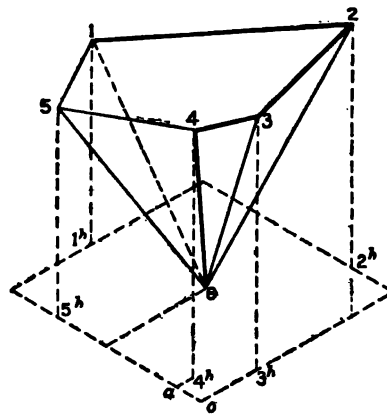


Fig. 18.

figures. The horizontal projection of point 3 is found in isometric at 3^h at the same distance from o as in the plan, that is, any distance which in plan is parallel to a side of the circumscribing rectangle is shown in isometric in its true length and parallel to the corresponding side of the isometric rectangle. If point 3 were on the horizontal plane its isometric would be 3^h , but the point is at the vertical height above H given in the elevation, hence lay off above 3^h this vertical height, obtaining the actual isometric of the point. To locate 4, draw 4^a parallel to the

side of the rectangle, then lay off oa and $a4^h$, giving what may be called the isometric plan of 4. Next the vertical height taken from the elevation locates the isometric of the point in space.

In a like manner all of the corners of the pyramid, including the apex, are located. The rule is, locate first in isometric the horizontal projection of a point by one or two 30° co-ordinates, then vertically above this point its height as taken from the elevation. The shade lines cannot be determined here by applying the 30° or 60° triangle, owing to the obliquity of the faces. Since

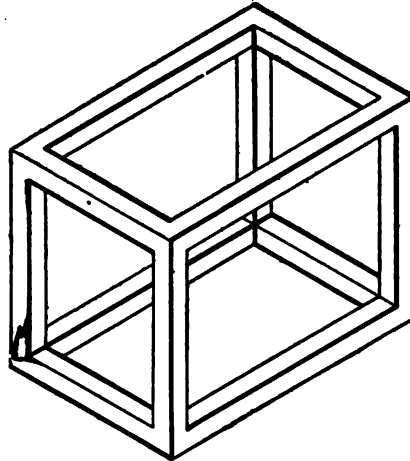


Fig. 19.

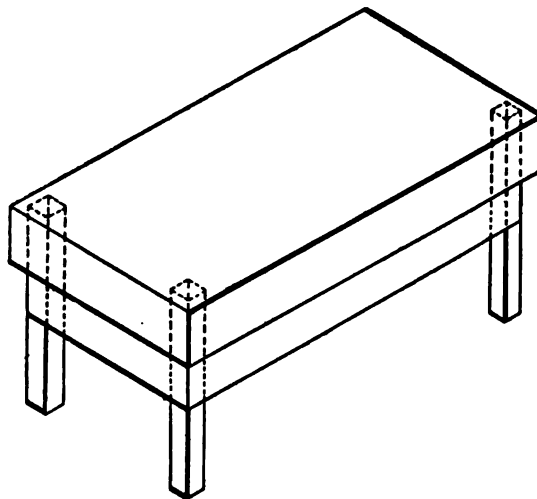


Fig. 20.

the right front corner of the rectangle in plan was made the point o in isometric, the shade lines must be the same in isometric as

in actual projection, so if these can be determined in Fig. 17, they may be applied at once to Fig. 18.

The shade lines in Fig. 17 are found by a short method which is convenient to use when the exact shade lines are desired,

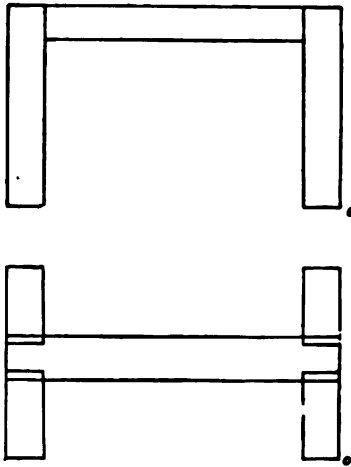


Fig. 21.

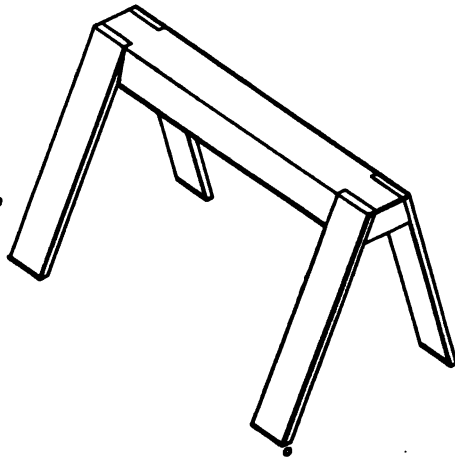


Fig. 22.

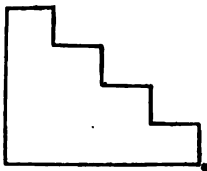


Fig. 23.

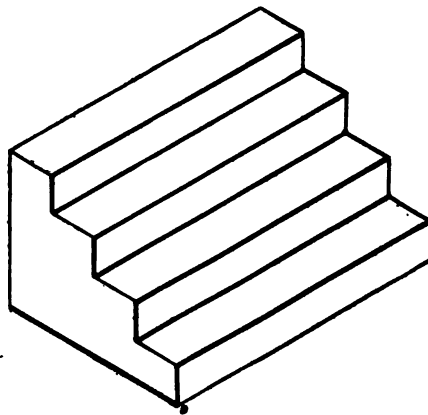


Fig. 24.

and when they cannot be determined by applying the 45° triangle. A plane is taken at 45° with the horizontal plane, and parallel to the direction of the ray of light, in such a position as to cut all the surfaces of the pyramid, as shown in elevation. This plane

is perpendicular to the vertical plane, hence the section it cuts from the pyramid is readily found in plan by projection. This plane contains some of the rays of light falling upon the pyramid, and we can tell what surfaces these rays strike and make light by noticing on the plan what edges of the section are struck by the projections of the rays of light. That is rs , st , and tu receive the rays of light, hence the surfaces on which these lines lie are light. rs is on the surface determined by the two lines passing through r and s , 2—1 and 1—5, hence the base; st surface 1—5—6, tu , 4—5—6. The other surfaces are

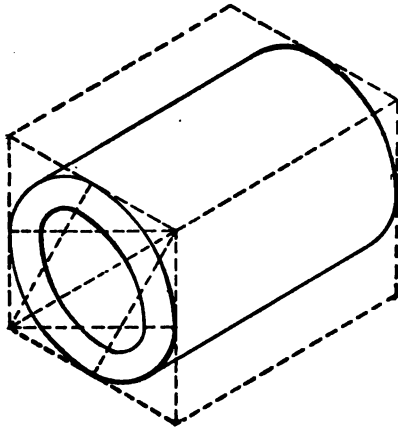


Fig. 25.

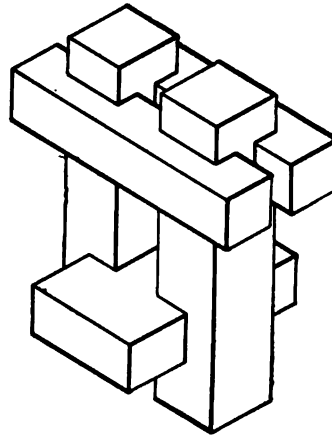


Fig. 26.

dark, hence the edges which are between the light and dark faces are the shade lines.

Whenever it is more convenient, a plane parallel to the ray of light and perpendicular to H may be taken, the section found in elevation, and the 45° triangle applied to this section. The same method may be used to determine the exact shade lines of a cone or cylinder in an oblique position.

Figs. 19 to 26 give examples of the isometric of various objects. Fig. 21 is the plan and elevation, and Fig. 22 the isometric of a carpenter's bench. In Fig. 26, take especial notice of the shade lines. These are put on as if the group was made in one piece, and the shadows cast by the blocks on one another

are disregarded. All upper horizontal faces are light, all left-hand (front and back) faces light, and the rest dark.

OBLIQUE PROJECTIONS.

In oblique projection, as in isometric, the end sought for is the same — a more or less complete representation in one view of any object. Oblique projection differs from isometric in that one face of the object is represented as if parallel to the vertical plane of projection, the others inclined to it. Another point of difference is that oblique projection cannot be deduced from orthographic projection, as is isometric.

In oblique projection all lines in the front face are shown in their true lengths and in their true relation to one another, and lines which are perpendicular to this front face are shown in their

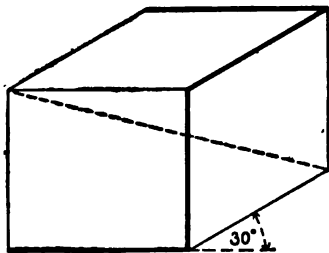


Fig. 27.

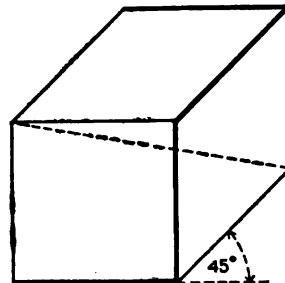


Fig. 28.

true lengths at any angle which may be desired for any particular case. Lines not in the plane of the front face nor perpendicular to it must be determined by coordinates, as in isometric. It will be seen at once that this system possesses some advantages over the isometric, as for instance in the representation of circles, as any circle or curve in the front face is actually drawn as such.

The rays of light are still supposed to be parallel to the same diagonal of the cube, that is, sloping downward, toward the plane of projection, and to the right, or downward, backward and to the right. Figs. 27, 28, and 29 show a cube in oblique projection, with the 30°, 45° and 60° slant respectively. The dotted diagonal represents for each case the direction of the light, and the shade lines follow from this.

The shade lines have the same general position as in isometric drawing, the top, front and left-hand faces being light. No matter what angle may be used for the edges which are perpendicular to

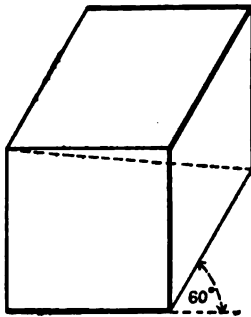


Fig. 29.

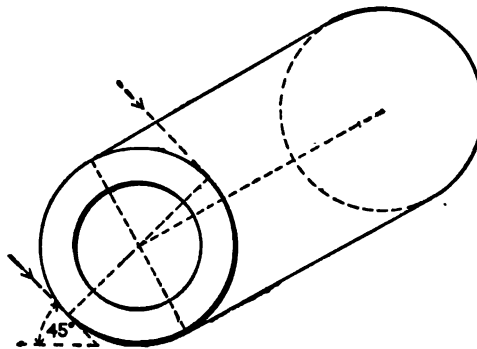


Fig. 30.

the front face, the projection of the diagonal of the cube on this face is always a 45° line, hence for determining the shade lines on any front face, as the end of the hollow cylinder in Fig. 30, the 45° line is used exactly as in the elevation of ordinary projections.

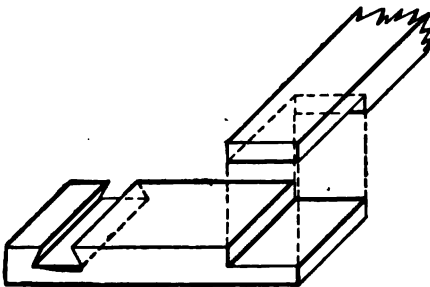


Fig. 31.

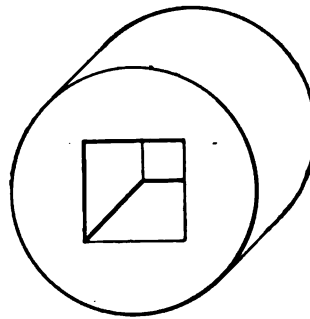


Fig. 32.

Figs. 31, 32, 33 and 35 are other examples of oblique projection. Fig. 33 is a crank arm.

The method of using co-ordinates for lines of which the true lengths are not shown is illustrated by Figs. 34 and 35. Fig. 35 represents the oblique projection of the two joists shown in plan and elevation in Fig. 34. The dotted lines in the elevation (see Fig. 34) show the heights of the corners above the horizontal

stick. The feet of these perpendiculars give the horizontal distances of the top corners from the end of the horizontal piece.

In Fig. 35 lay off from the upper right hand corner of the

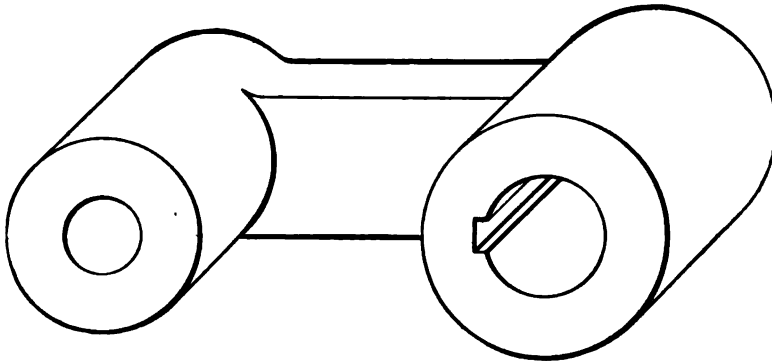


Fig. 33.

front end a distance equal to the distance between the front edge of the inclined piece and the front edge of the bottom piece (See Fig. 34). From this point draw a dotted line parallel to the

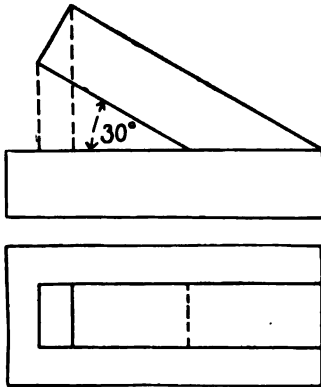


Fig. 34.

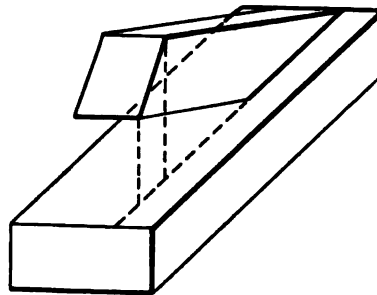


Fig. 35.

length. The horizontal distances from the upper left corner to the dotted perpendicular are then marked off on this line. From these points verticals are drawn and made equal in length to the dotted perpendiculars of Fig. 34, thus locating two corners of the end.

LINE SHADING.

In finely finished drawings it is frequently desirable to make the various parts more readily seen by showing the gradations of light and shade on the curved surfaces. This is especially true of such surfaces as cylinders, cones and spheres. The effect is obtained by drawing a series of parallel or converging lines on the surface at varying distances. Sometimes draftsmen vary the width of the lines themselves. These lines are farther apart on the lighter portion of the surface, and are closer together and heavier on the darker part.

Fig. 36 shows a cylinder with elements drawn on the surface equally spaced, as on the plan. On account of the curvature of the surface the elements are not equally spaced on the elevation, but give the effect of gradation of light. The result is that in elevations the distances between the elements gradually lessen from the center toward each side; thus showing that the cylinder is convex. The effect is intensified, however, if the elements are made heavier, as well as closer together, as shown in Figs. 37 to 43.

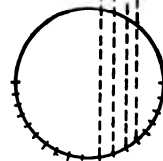


Fig. 36.

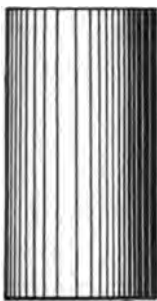


Fig. 37.

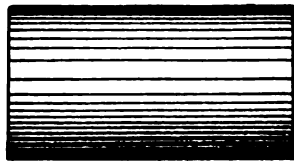


Fig. 38.

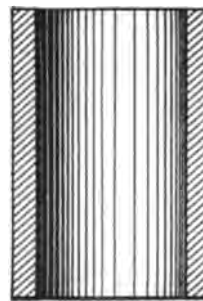


Fig. 39.

Cylinders are often shaded with the light coming in the usual way, the darkest part commencing about where the shade line would actually be on the surface, and the lightest portion a

little to the left of the center. Fig. 37 is a cylinder showing the heaviest shade at the right as this method is often used. Considerable practice is necessary in order to obtain good results, but

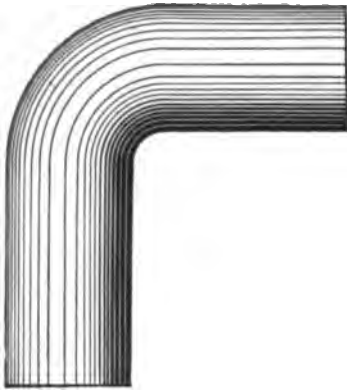


Fig. 40.

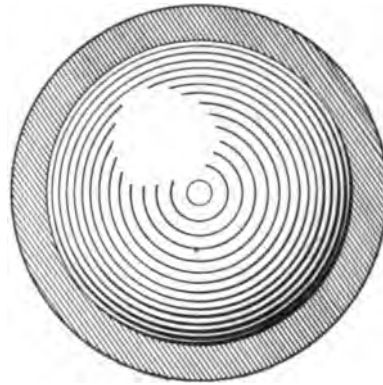


Fig. 41.

in this as in other portions of mechanical drawing, perseverance has its reward.

Fig. 38 represents a cylinder in a horizontal position, and

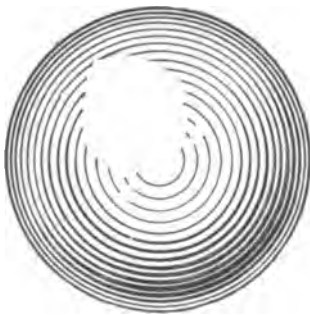


Fig. 42.



Fig. 43.

Fig. 39 represents a section of a hollow vertical cylinder.

Figs. 40 to 43 give other examples of familiar objects.

In the elevation of the cone shown in Fig. 43 the shade lines

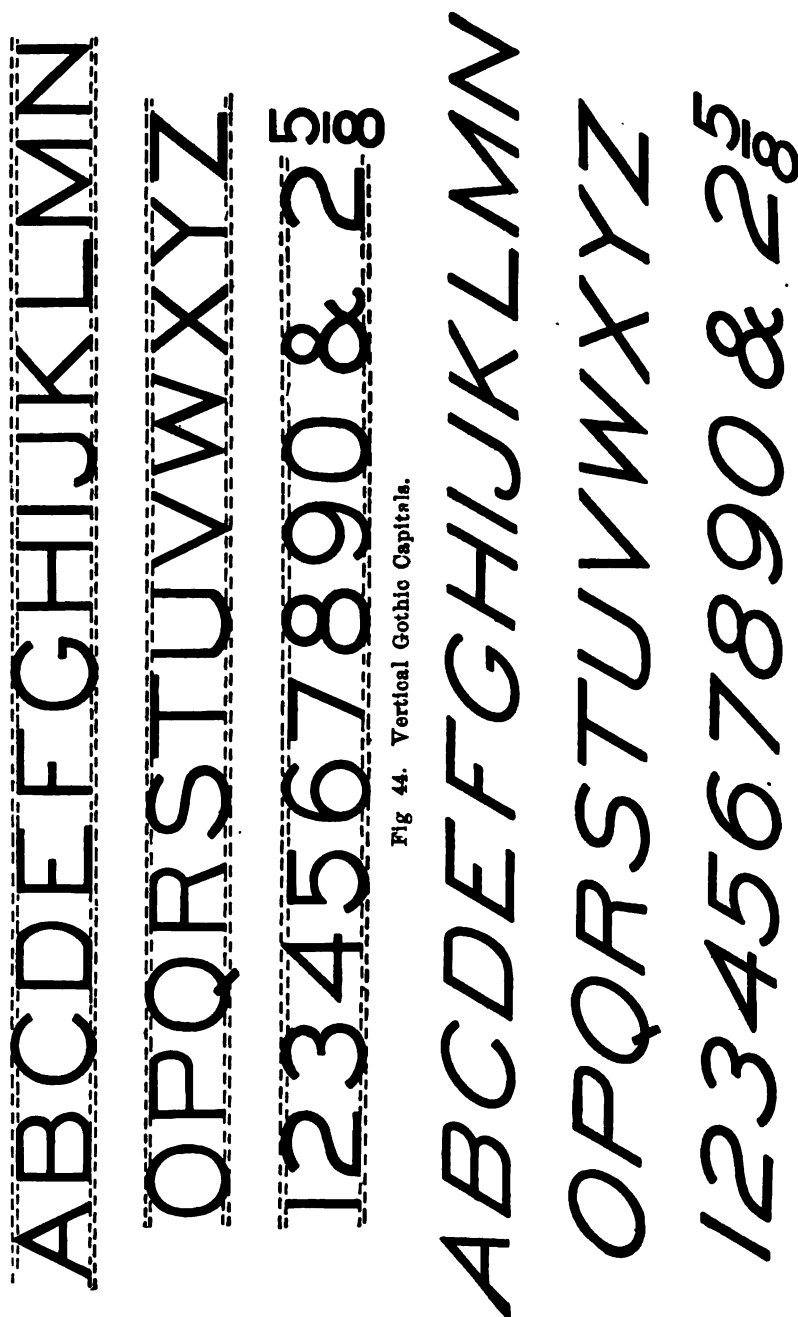
should diminish in weight as they approach the apex. Unless this is done it will be difficult to avoid the formation of a blot at this point.

LETTERING.

All working drawings require more or less lettering, such as titles, dimensions, explanations, etc. In order that the drawing may appear finished the lettering must be well done. No style of lettering should ever be used which is not perfectly legible. It is usually best to use plain, easily-made letters which present a neat appearance. Small letters used on the drawing for notes or directions should be made free hand with an ordinary writing pen. Two horizontal guide lines should be used to limit the height of the letters; after a time, however, the upper guide line may be omitted.

In the early part of this course the inclined Gothic letter was described and the alphabet given. The Roman, Gothic and block letters are perhaps the most used for titles. These letters being of larger size are generally made mechanically, that is, the drawing instruments are used in their construction. In order that the letters may appear of the same height, some of them, owing to the shape, must be made a little higher than the others. This is the case with the letters curved at the top and bottom, such as C, O, S, etc., as shown somewhat exaggerated in Fig. 44. The letter A should extend a little above and V a little below the guide lines because if made of the same height as the others they will appear shorter. This is true of all capitals, whether of Roman, Gothic, or other alphabets. In the block letter, however, they are frequently all of the same size.

There is no absolute size or proportion of letters, as the dimensions are regulated by the amount of space in which the letters are to be placed, the size of the drawing, the effect desired, etc. In some cases letters are made so that the height is greater than the width, and sometimes the reverse; sometimes the height and width are the same. This last proportion is the most common. Certain relations of width, however, should be observed. Thus, in whatever style of alphabet used, the W should be the widest letter; J the narrowest, M and T next widest to W, then A and B. The other letters are of about the same width.



In the vertical Gothic alphabet, the average height is that of B, D, E, F, etc., and the additional height of the curved letters and the A and V is very slight. The horizontal cross lines of such letters as E, F, H, etc., are slightly above the center; those of A, G and P slightly below.

For the inclined letters, 60° is a convenient angle, although

abcdefghijklmnopqrstuvwxyz

Fig. 45.

they may be at any other angle suited to the convenience or fancy of the draftsman. Many draftsmen use an angle of about 70°.

The letters of the Roman alphabet, whether vertical or inclined, are quite ornamental in effect if well made; the inclined Roman being a particularly attractive letter, although rather difficult to make. The block letter is made on the same general plan

abcdefghijklmnopqrstuvwxyz

Fig. 46.

as the Gothic, but much heavier. Small squares are taken as the unit of measurement as shown. Its use is not advocated for general work, although if made merely in outline the effect is pleasing. The styles of numbers, corresponding with the alphabets of capitals given here are also inserted. When a fraction, such as $2\frac{1}{2}$ is to be made, the proportion should be about as shown.

A B C D E F G H I J K L M N
 O P Q R S T U V W X Y Z
 1 2 3 4 5 6 7 8 9 0 & 2⁵/₈

Vertical Roman Capitals.

A B C D E F G H I J K L M N
O P Q R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 0 & 2⁵/₈

Inclined Roman Capitals.

For small letters, usually called lower case letters, the height may be made about two-thirds that of the capitals. This proportion, however, varies in special cases.

The principal lower case letters in general use among draftsmen are shown in Figs. 45, 46, 47 and 48. The Gothic letters

abcdefghijklmnopqrstuvwxyz

Fig. 47.

shown in Figs. 45 and 46 are much easier to make than the Roman letters in Figs. 47 and 48. These letters, however, do not give as finished an appearance as the Roman. As has already been stated in Mechanical Drawing Part I, the inclined letter is easier to make because slight errors are not as apparent.

One of the most important points to be remembered in lettering is the spacing. If the letters are finely executed but poorly

abcdefghijklmnopqrstuvwxyz

Fig. 48.

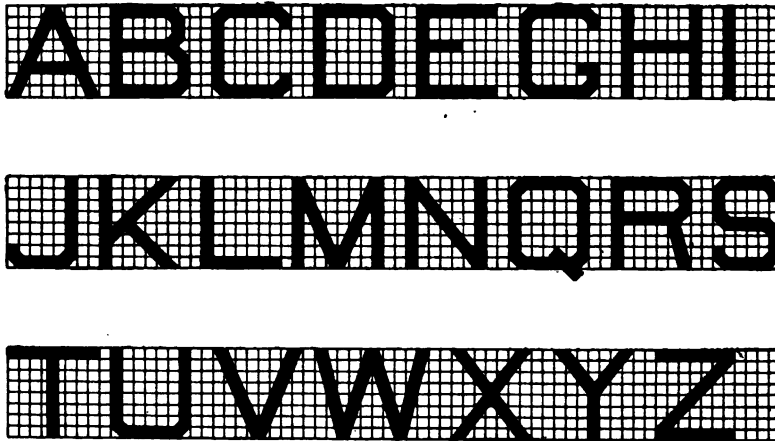
spaced the effect is not good. To space letters correctly and rapidly requires considerable experience, and rules are of little value on account of the many combinations in which letters are found. A few directions may, however, be found helpful. For instance take the word TECHNICALITY, Fig. 49. If all the spaces were made equal, the space between the L and I would appear to be too great, and the same would apply to the space between the I and T. The space between the H and N and the

N and I would be insufficient. In general, when the vertical side of one letter is followed by the vertical side of another, as H E, H B, I R, etc., the maximum space should be allowed. Where T and A come together the least space is given, for in this case the top of the T frequently extends over the bottom of the A.

TECHNICALITY

Fig. 49.

In general, the spacing should be such that a uniform appearance is obtained. For the distances between words in a sentence a space of about $1\frac{1}{2}$ the width of the average letter may be used. The space, however, depends largely upon the desired effect.



Block Letters.

For large titles, such as those placed on charts, maps, and some large working drawings, the letters should be pencilled before inking. If the height is made equal to the width considerable time and labor will be saved in laying out the work. This is especially true with such Gothic letters as O, Q, C, etc., as these letters may then be made with compasses. If the letters are of

sufficient size the outlines may be drawn with the ruling pen or compasses, and the spaces between filled in with a fine brush.

The titles for working drawings are generally placed in the lower right-hand corner. Usually a draftsman has his choice of letters, mainly because after he has become used to making one style he can do it rapidly and accurately. However, in some drafting rooms the head draftsman decides what lettering shall be used. In making these titles the different alphabets are selected to give the best result without spending too much time. In most work the letters are made in straight lines, although we frequently find a portion of the title lettered on an arc of a circle.

CONNECTING ROD
FOR
BEAM ENGINE

SCALE 3 INCHES = 1 FOOT

PORTLAND COMPANY'S WORKS

JULY 10, 1894

Fig. 50.

In Fig. 50 is shown a title having the words "CONNECTING ROD" lettered in the arc of a circle. To do this work requires considerable patience and practice. First draw the vertical center line as shown at C in Fig. 50. Then draw horizontal lines for the horizontal letters. The radii of the arcs depend upon the general arrangement of the entire title, and is a matter of taste. The difference between the arcs should equal the height of the letters. After drawing the arc the letters should be sketched in pencil to find their approximate positions. After this

A B C D E F G H I J K L M N

O P Q R S T U V W X Y Z

Architectural Capitals.

A B C D E F G H I K L M N

O P Q R S T V W X Y Z

Architectural Capitals.

is done, draw radial lines from the center of the letters to the center of the arcs. These lines will be the centers of the letters as shown at A, B, D and E. The vertical lines of the letters should not radiate from the center of the arc, but should be parallel to the center lines already drawn; otherwise the letters will appear distorted. Thus in the letter N the two verticals are parallel to the line A. The same applies to the other letters in the

THE FOSTER SAFETY STOP VALVE FOSTER ENGINEERING COMPANY.

FEBRUARY 6, 1899.

FULL SIZE.

Fig. 51.

alphabet. In making the curved letters, such as O and C, the centers of the arcs will fall upon these center lines, and if the compasses are used the lettering is a comparatively simple matter. In Fig. 51 is shown another title in which all of the letters are in horizontal lines.

WORKING DRAWINGS.

In Part III, the subject of working drawings and the practices usually followed in making and using them were discussed briefly. We will now study working drawings more thoroughly and see how the principles of orthographic projection are made of practical use. We shall see, as we go on, that to a great extent the theoretical methods already learned in the study of projections are used in practical drawings. Nevertheless there are certain instances in which actual practice differs slightly from the theory.

We shall also find that all draftsmen do not follow the same customs in the matter of minor details, but that in many cases there are several ways of representing objects, all of which may be equally correct, one draftsman using one method either because he prefers it or because it best serves the purpose for which his particular work is being done, while another draftsman uses a different method. The more important principles and customs, however, are pretty well established.

A study of the subject of working drawings should, first, teach us the methods of the best drafting-rooms; second, should train our judgment so that we may be able to decide how best to represent the particular object which we have to draw; third, should train our hand and eye so that we may be able to make a clear, neat and well-executed drawing, without unnecessary expenditure of time.

Definition of Working Drawing. A working drawing of any object is a drawing which completely describes the object in every particular, showing its form, size, material, finish, and all other details, so that a workman may take the drawing and without any further instructions make the object exactly as the draftsman intended it to be made. The drawing is, therefore, a sort of language, by which the man who designs the object describes it to the man who is to make it.

Aside from drawings of buildings, etc., that is, architectural drawings, the greater part of the working drawings which are made are for machines, and we will consider chiefly the latter, or, as they are called, machine drawings. These drawings are almost always orthographic projections, as this is by far the easiest and best way to represent a machine or a part of a machine. Sometimes, when it is desired to give a sort of bird's-eye view of a machine, an isometric or an oblique projection is made, but this method involves so much labor that it is seldom used.

Lines. In order to make a drawing perfectly clear, and to avoid confusing one line with another, different kinds of lines are used for different purposes. Fig. 52 shows the six most common kinds used.

The ordinary *full lines* are used to represent visible lines of the object which is being drawn.

The *invisible lines* are used to represent lines of the object which would be hidden from sight if a person looked in the direction in which he imagines himself to be looking while he is drawing it.

The use of the *shade lines* will be explained later.

Center lines are used to connect different views of an object, the line being drawn through the center of the piece and extending through both views. Locations of holes are usually shown by having two center lines drawn at right angles to each other through their centers, and the position of these center lines located. Wherever a dimension is to be given to the center of a piece a center line is drawn through the piece and the dimension given to this line.

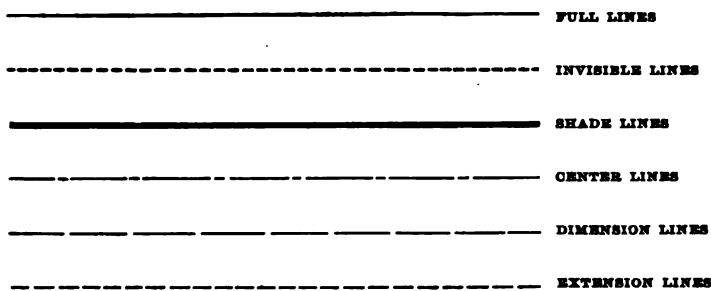


Fig. 52.

Extension lines are sometimes used to connect two views of a piece, but, wherever it is possible to use a center line, instead, the latter is preferable. The principal use of extension lines is, as the name implies, to extend the lines of the object so as to give dimensions between them.

Dimension lines are used in giving dimensions from one line or point to another.

The ordinary lines and the invisible lines should be made of the same width; the shade lines should be made considerably heavier, and the center lines, extension lines and dimension lines should be lighter.

Location of Views. In our preceding study of projections we imagined our object to be held in the angle formed by two

planes which intersect at right angles, the planes and the object being supposed to be in the position represented in Fig. 53, the

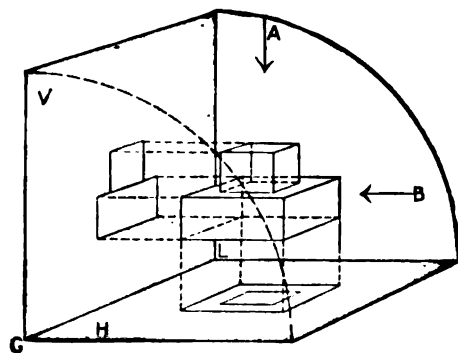


Fig. 53.

horizontal plane H being below the object, and the vertical plane V being beside the object. We then projected down to the horizontal plane and represented there the object as it would appear if seen squarely in the direction indicated by arrow A. We next projected into the vertical plane, and represented the object as it

would appear if the line of vision took the direction of the arrow B. Our planes, with the horizontal and vertical projections of the object on them, when laid out flat, as a sheet of paper is when we actually draw on it, would appear as in Fig. 54, the horizontal projection, or top view, being *underneath* the vertical projection, or side view. This is the practice followed by some draftsmen in making working drawings. Many of the best draftsmen, however, think that it is not as clear and convenient to have the top view of the object underneath the side view, but that it is better to have the view of the top above the other view. Consequently, it is becoming more and more a general custom to suppose the planes to be transparent and to be located with respect to the piece which is

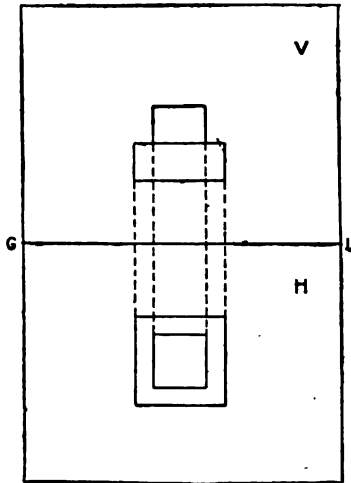


Fig. 54.

being drawn as shown in Fig. 55, the H plane being above the object and the V plane in front of the object. They then draw on the H plane the object as it appears when looking at it

through the transparent plane in the direction indicated by arrow C, and on the V plane the object as it appears when looking in direction of arrow D. Now, when the two planes are laid out flat, the top view is above the side view, as in Fig. 56.

Another way of showing this is to suppose the object to be located in a transparent box, and that we look at it from the top and the various sides of the box, and draw on these sides the object as it appears from that side. Then, if the sides of the box are laid out flat, the side view

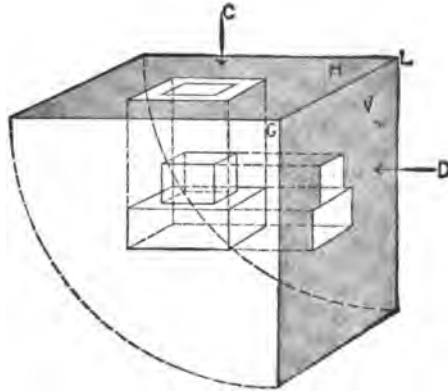


Fig. 55.

will come in the middle, with the top view above, the view of the bottom underneath, the view of the right-hand side on the right, and the view of the left-hand side on the left.

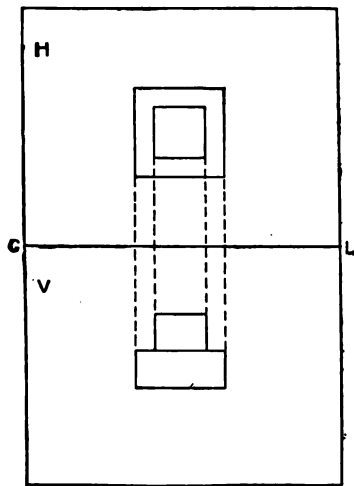


Fig. 56.

From now on, in our work on drawing, we shall follow this rule.

Cross-sections. Very often it occurs that a piece is hollow and the inside construction is more or less complicated, so that if in the drawing the outside view is shown, with the invisible interior drawn in dotted lines, the latter are so confused that the drawing is not easily understood. For this reason it is often convenient to imagine the piece to be cut open, and to

draw it as if we were looking directly at the inside. Such a drawing of a piece is called a cross-section of the piece. The material which must be cut if the object were actually split open is then crosshatched, different kinds of crosshatching being

used for different materials. Fig. 57 shows the kinds of cross-hatching in ordinary use.

Fig. 58 shows a plan and elevation of a simple piece with a hole through it, the hole being shown in the elevation by dotted lines. Fig. 59 shows a plan and a cross-section of the same piece, the cross-section being drawn as if we were looking in the same direction as in the elevation of Fig. 58, but in Fig. 59 the front half is supposed to be cut away and we are looking at the inside of the back half. It will be observed that even on a piece as

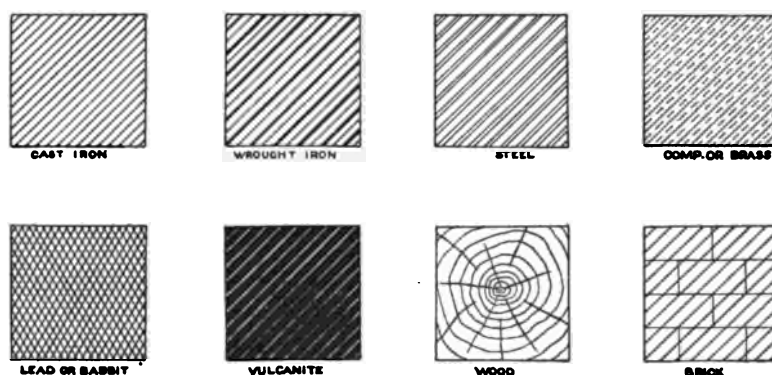


Fig. 57.

simple as the one here shown, the shape of the interior is much clearer from the cross-section than from the elevation, and on a more complicated piece the same will be true to a greater extent.

It should be borne in mind that ordinarily in making a cross-section we show not only those parts of the object which lie in the plane in which it is supposed to be cut, but also all which lie back of that plane.

Sometimes it is desirable to show the inside and the outside of a piece on the same view. Fig. 60 shows the same piece as in Fig. 58, but in Fig. 60 the left-hand half of the lower view is an elevation and the right-hand half is a cross-section, the section and the elevation each extending to the center and being separated by a center line. This is as if one-quarter of it were cut away, the cuts being made along the lines C A and C B of the plan view.

Of course this combination of an elevation and cross-section

can be used only when the right-hand and left-hand halves of the piece are alike.

Shade Lines. In order to make drawings easier to read, and to make the parts of the object stand out more clearly, shade lines are often put on the drawing. The general principle which determines what lines shall be shade lines is the same as that which governs shade lines already studied under the subject of projections. If, however, this theoretical principle were to be followed out exactly on drawings of machines, and other complicated drawings, it would involve a great deal of time and labor.

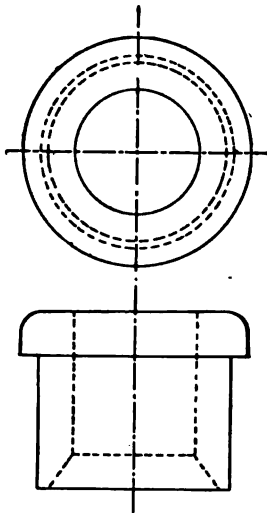


Fig. 58.

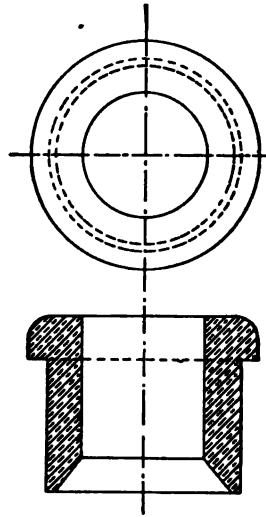


Fig. 59.

Consequently, most draftsmen place shade lines on all lines which represent lower and right-hand edges if these edges are sharp.

The contour lines of cylinders, cones and other rounded surfaces should not be shade lines, although some draftsmen shade them. If the cylinder is drawn in cross-section, however, the edge should be shaded, as the intersection of the plane and cylindrical surface is a sharp edge.

All views are shaded alike, and both are shaded as though they were elevations. The ray of light is supposed to come over

the left shoulder of the draftsman, as he faces the paper, at such an angle that the projection of the ray of light on the drawing paper is in the direction of the arrow in Fig. 61.

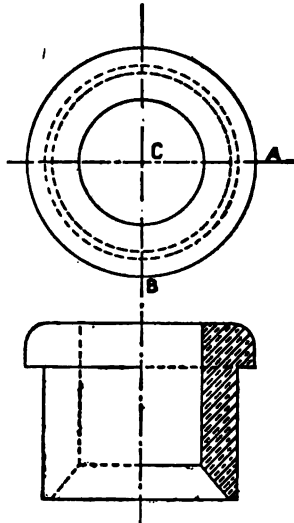


Fig. 60.

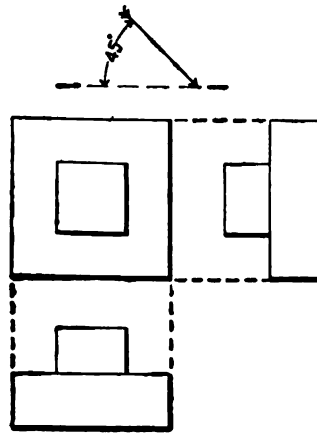


Fig. 61.

Figs. 61 to 68 show some of the most common shapes met with in drawings, and illustrate how the shade lines are placed on each. Fig. 61 is an elevation, plan, and side view of a rectangular

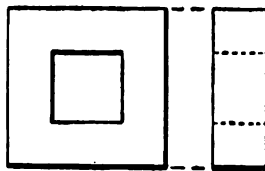


Fig. 62.

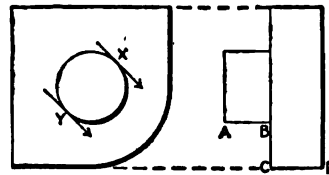


Fig. 63.

prism with a smaller one resting on top of it. Fig. 62 is a plan and side view of a rectangular prism with a rectangular hole through it. It is to be noticed that the shade lines come on the upper and left-hand sides of the hole, since these lines are the

lower and right-hand edges of the material which surrounds the hole. Fig. 63 is a plan and side view of a rectangular prism with one corner rounded, and with a cylinder resting on it. Here the lines A B and C D are not shaded, since they are the contour lines of curved surfaces. In the plan view, the lower right-hand part of the circle, between X and Y, is shaded. To find these points X and Y, draw two lines tangent to the circle and making an angle of 45° with the T-square line as shown by the arrows; X and Y are the points where the arrows are tangent to the circle. Fig. 64 is a plan, elevation and cross-section of a cylinder.

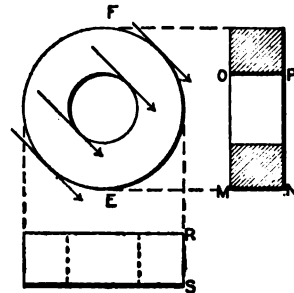


Fig. 64.

Here, in the plan, the larger circle is shaded on the lower side, and the circle which represents the hole is shaded on the upper side. The points where the shade begins are determined as explained for Fig. 63. The lines M N and O P are shaded since,

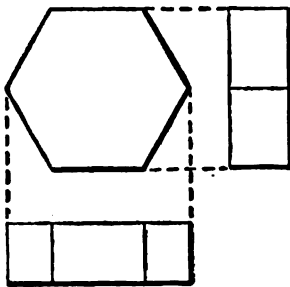


Fig. 65.

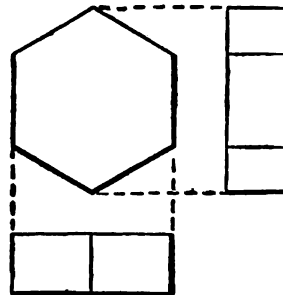


Fig. 66.

as the cylinder is supposed to be cut open, these lines now represent sharp edges. Fig. 65 is a plan, elevation and side view of a hexagonal prism with its long diameter parallel to the bottom of the paper. Fig. 66 is the same except that here the short diameter of the prism is parallel to the bottom of the paper. Fig. 67 is a plan and end view of a rectangular block with a wide slot of the shape H I J K M L O N, cut through it lengthwise. The main point to which attention should be called here is that the line

C D is shaded, although the slot might be so deep that the light might not strike in there because of the shadow of the projecting lip marked in the side view G H I. Fig. 68 is a cross-section and end view of a circular cylinder with a large hole extending part way through and a smaller hole extending the rest of the way. The small circle in the end view is shaded, although it is so far in that no light could strike it.

The student should study these figures carefully, and before

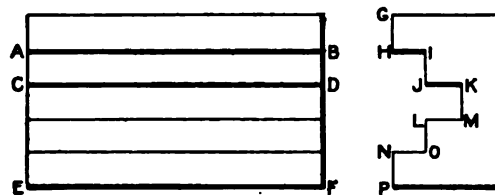


Fig. 67.

leaving them should understand what each figure means and how the shade lines are determined, so that when he meets similar forms in machine drawings he may know where the shade lines should be placed.

Dimensions. In giving the distance from one line to another, a dimension line is drawn between the two lines and arrowheads

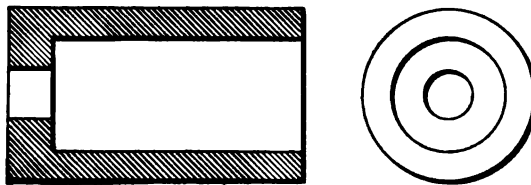


Fig. 68.

are placed at each end of the dimension line; the points of the arrowheads being *exactly* on the lines to which the measurement is being given. At a convenient place between the arrowheads a space is left in the dimension line for the figure.

Fig. 69 is a plan and elevation of a rectangular piece with a

cylinder on the center of its upper surface, and with four holes through it; the holes being symmetrically located with respect to the center line of the piece; that is, the holes A and B are just as far above the center line E F as C and D are below it, and the holes B and D are just as far to the right of the center line G H as A and C are to the left of it. The fact that the cylinder is on the center of the rectangular piece is shown by the lines E F and G H being drawn through the center of the circle in the plan view, these lines being the center lines both of the cylinder and of the rectangular piece. If the cylinder were not on the center, two other center lines would be drawn through the circle and the dimensions given from each of these lines to the center lines of the rectangular piece, or to the edges of the piece. The fact that the holes are symmetrically located is shown by the dimensions being given between the center lines of the holes and no dimensions being given from these center lines to the center lines of the piece.

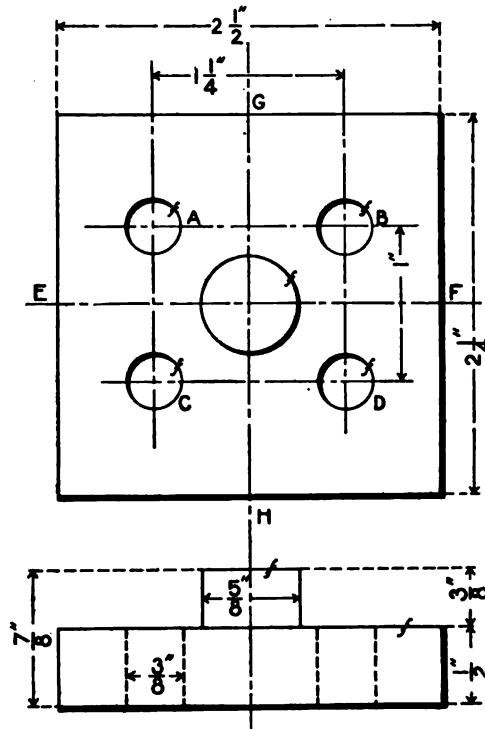


Fig. 69.

Fig. 70 shows how the piece might be dimensioned if the cylinder were not on the center of the rectangular piece and the holes were not symmetrically located with respect to the center of the rectangular piece.

If the centers of a set of holes are so located that a circle can be drawn through them, we always locate the holes by drawing a

sion in Fig. 70, and from the right hand for dimension lines which are vertical, as the $2\frac{1}{4}$ " dimension in the same figure. Dimensions should never be placed on center lines if it can be avoided.

If a dimension is given in one view of an object, the same dimension need not be repeated in the other views.

In putting on fractions it is better to have the line which

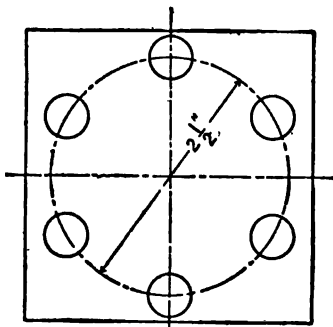


Fig. 71.

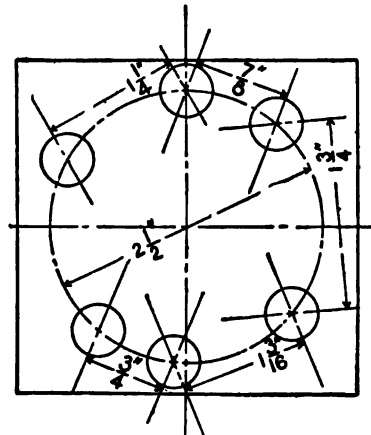


Fig. 72.

divides the numerator and denominator of the fraction extend in the same direction as the dimension line rather than at an angle; that is, the fraction would appear thus, $\frac{1}{2}$, rather than $\frac{1}{2}$.

Finished Surfaces. Since a working drawing is not only to

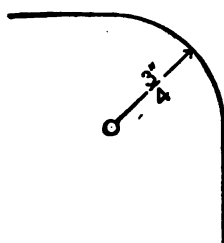


Fig. 73.



Fig. 74.

show the shape and size of the object which it represents, but is to describe it completely, it is essential that there should be some means of distinguishing between the surfaces of the object which are to be left rough as they come from the forge or from the foundry, and the surfaces which are to be finished. Any surface

which has been smoothed off in a lathe, planer, or any machine tool, or has been filed or scraped, is called a finished surface, and is indicated on a drawing by a letter placed on the *edge view* of this surface. In Fig. 69 the whole of the cylindrical part is finished, also the top of the rectangular part. The holes are also finished. The student should notice carefully how the finish marks are used to indicate this fact.

If a piece is to be finished all over, it should be marked “*f* all over.” If it is desired to specify what kind of finish is to be put on a surface, that is, whether rough turned, smooth turned, filed, scraped, etc., a note may be made to that effect.

On some conspicuous place on the drawing the words “*f* means finish” should be printed, so that there may be no misunderstanding on the part of a person examining the drawing.

Material. The material of which the piece is to be made should be indicated plainly. If any part of the drawing is a cross-section, the crosshatching might show the material, provided that in some conspicuous part of the drawing a sample of the crosshatching is shown and the material which it represents is stated. It is better, however, to mark on or near each piece, in plain letters, the material of which it is to be made.

PLATES.

Four plates (XVI to XIX inclusive) are to be drawn, one involving problems in isometric and one in oblique projection; a plate on lettering and a working drawing will give the student some practical work. The plates are to be of the same size as the preceding plates; border lines, name, etc., also to be the same. As Plate XVIII is composed entirely of capitals, the student may obtain practice in free-hand lettering by laying out a plate in the same manner as Plate I and lettering all four rectangles; using the same letters and words as those in the lower right-hand rectangle of Plate I. This plate will be excellent practice and will show the improvement made since taking up Plate I. The plate is optional and should be called Plate A.

PLATE XVI.

Isometric Drawings.

1. Make isometric drawing of the block given by projections in Fig. 75. A square hole extends through the block, and a groove is made across the front. The dimensions are to be those given in the figure. Locate isometric of the lower right-hand corner $3\frac{3}{4}$ inches from left border line, and 4 inches from upper border line.

2. Make isometric of prism shown by projections in Fig. 76. As the edges of the prism will not be isometric lines, it is neces-

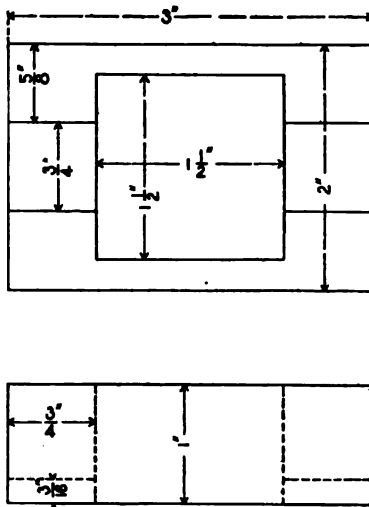


Fig. 75.

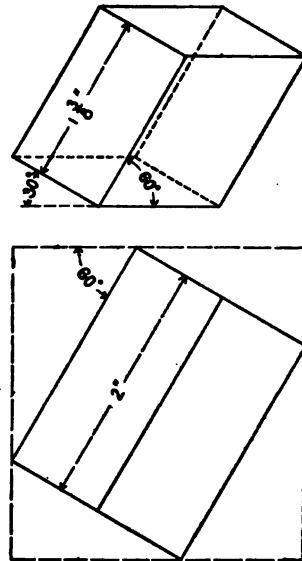
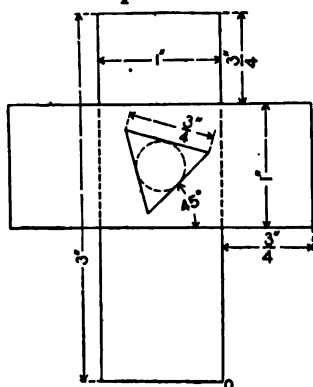


Fig. 76.

sary to circumscribe a rectangle about the plan as shown by dotted lines in the figure; locate isometric by co-ordinates, as previously explained. As the figure is not full size on this page it must be constructed actual size on a separate sheet of paper from the given dimensions, a rectangle circumscribed, then the isometric constructed from this. Notice that the elevation of the end of the prism is a rectangle. The length of the short side of the end is omitted, but the highest corner is determined

by being vertically above the lowest corner. The lower right corner of the rectangle is to be the front corner of isometric rectangle, and located $4\frac{1}{4}$ inches from top margin and $7\frac{1}{2}$ inches from left.

3. Make isometric drawing from group of blocks shown in plan of elevation in Fig. 77. O is to be the front corner and located $2\frac{1}{4}$ inches from the right-hand margin and $5\frac{3}{8}$ inches from the top.



The horizontal triangular block has for the elevation an equilateral triangle, the center of which coincides with the center of the square formed by the edges of the other two blocks, and the lower right-hand edge makes 45 degrees with the horizontal. In order to make the isometric of this triangular prism it is simply necessary to construct in another figure an actual one-inch square. With the triangle properly placed, locate the corners of the triangle by co-ordinates from the edges, then transfer the square and co-ordinates to the isometric drawing.

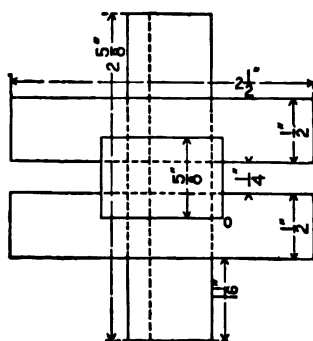


Fig. 77.

4. Draw isometric of a portable closet. Make height three inches, depth one and one-quarter inches, and width two and one-half inches. The width of the closet is to be shown in the left-hand isometric face. The front corner is to be $4\frac{1}{2}$ inches from the left, and $\frac{1}{2}$ inch from the lower border line.

A door is made in the left front of the closet $1\frac{1}{2}$ inches wide and $2\frac{1}{2}$ inches high. The door is placed centrally in the front of the closet; the bottom edge at the height of the floor of the closet, the hinges of the door are on the left-hand side, and the door is to be opened to an angle of 90 degrees. The thickness of the material of the closet and door is $\frac{1}{8}$ inch. The door is hung so that when closed it will be flush with the front of the closet.

5. Make the isometric drawing of the flight of steps and end walls as shown by the end view in Fig. 78. The lower right corner is to be located $\frac{1}{2}$ inch from the lower and $4\frac{3}{8}$ inches from the right-hand margin. The base of the end wall is $3\frac{1}{8}$ inches long, and the height is $2\frac{1}{4}$ inches. Beginning from the back of the wall the top is horizontal for $\frac{5}{8}$ inch, the remainder of the outline being composed of arcs of circles whose radii and centers are given in the figure. The thickness of the end walls is $\frac{3}{8}$ inch, and both ends are alike. There are to be five steps; each rise is to be $\frac{3}{8}$ inch and each tread $\frac{1}{2}$ inch except that of the top step which is $\frac{3}{4}$ inch. The first step is located $\frac{3}{8}$ inch back from the corner of the wall. The end view of the wall should be constructed on a separate sheet of paper from the dimensions given; the points on the curve located by horizontal co-ordinates from the vertical edge of the wall, then these co-ordinates transferred to the isometric drawing. After the isometric of one curved edge has been made, the others can be readily found from this. The width of the steps inside the walls is $2\frac{1}{2}$ inches.

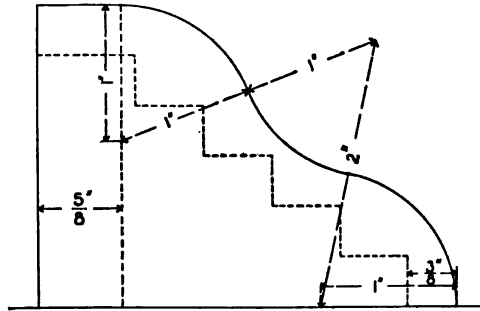


Fig. 78.

PLATE XVII.

Oblique Projections.

In this plate two of the same figures are to be drawn as in Plate XVI, thus affording an opportunity of contrasting the two systems. The angle to be used is 45 degrees, and the lower right corner used for the front in isometric is to be the lower right-hand corner of the front face. Dimensions of figures are to be the same as in Plate XVI, unless otherwise stated.

1. Draw the oblique objection of the portable closet. Locate the front lower right corner $4\frac{3}{8}$ inches from the left border line and $3\frac{1}{2}$ inches from the lower border line.

2. Draw the oblique projection of the flight of steps. Locate the lower right corner $3\frac{1}{2}$ inches from the right border line and $2\frac{3}{4}$ inches from the lower border line.

In inking place the shade lines on all figures. Invisible edges, except those of Problems 1 and 3 of Plate XVI, should be left out. Ink construction line using a light dotted line.

PLATE XVIII.

Lettering.

First lay out Plate XVIII in the same manner as previous plates. After drawing the vertical center line, draw light pencil lines as guide lines for the letters. The height of each line of letters is shown on the reproduced plate. The distance between the letters should be $\frac{1}{2}$ inch in every case. The spacing of the letters is left to the student. He may facilitate his work by lettering the words on a separate piece of paper and finding the center by measurement or by doubling the paper into two equal parts. The styles of letters shown on the reproduced plate should be used.

PLATE XIX.

Cylinder Head.

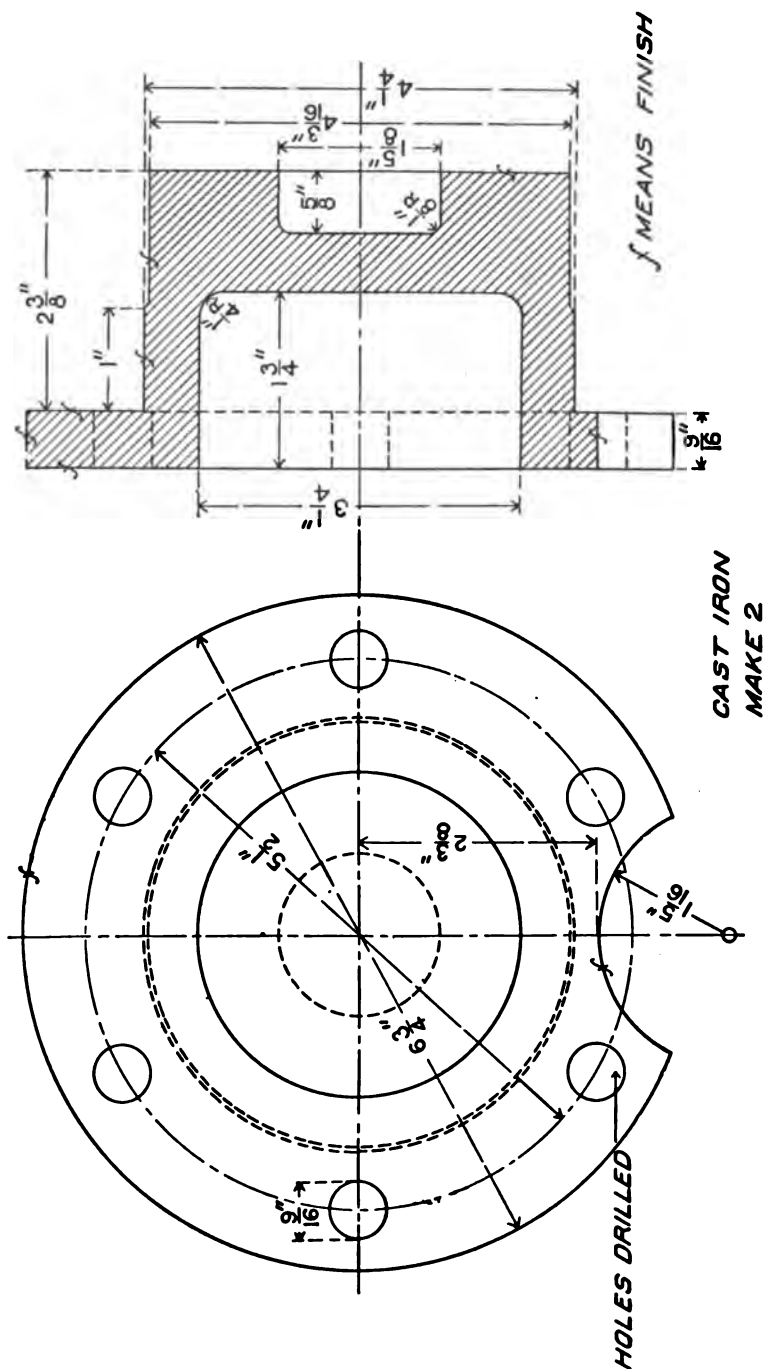
This plate consists of an end view and a cross-section of the cylinder head of a small engine. The center line is drawn half-way between the upper and lower border lines of the plate, and the two views are located along this center line so as to leave about equal spaces between the drawings and the right and left border lines, allowance being made for the space required for dimensions. About $\frac{3}{4}$ or 1" should be left between the two views.

The shade lines have not been put on the copy plate, but the student is expected to put them on his drawing, according to the methods already described for machine drawings.

The title and explanatory notes should be located so as to make the plate appear well balanced, and should not be crowded.

COURSE
IN
MECHANICAL DRAWING
MACHINE DRAWINGS
AND
PROJECTIONS
BOSTON, MASS., U.S.A.
1901

CYLINDER HEAD



MAY - 20. 1901.

HERBERT CHANDLER

CHICAGO, ILL.

SECTION 5.

MECHANICAL DRAWING.

PART V.

MACHINE DRAWING.

A machine consists of a number of parts, or groups of parts, so arranged and connected that, when power is applied at one part, definite motions and forces are transmitted to the other parts, which in turn do certain definite work. The parts of a machine may be divided in a general way into two classes: first, those parts which have or cause motion; and second, those which act as supports for the moving parts, such as frame, bearings, etc.

One of the groups of parts of a machine, arranged to accomplish some one particular result, is called a mechanism. Most machines are composed of several mechanisms, one doing one thing and another doing something else, and the whole working together to do the work for which the machine is designed. Take, for example, a metal planer; the gears, levers, etc., which cause the platen to move back and forth form one mechanism; the parts which feed the tool across form another mechanism, and so on, all the mechanisms taken together forming the machine.

Among the most common parts of machines are springs, screws, cams, pulleys and belts, and gears, and consequently it is necessary that a draftsman should understand how to draw these parts.

THE HELIX.

Since most coil springs and all screw threads depend upon a curve known as a helix, it will be necessary to know what a helix is, and how it can be drawn, before taking up the construction of the springs and screws.

Suppose we take a cylindrical piece of wood, such as is shown in Fig. 1, and a rectangular piece of paper, A B F E, with the side A B equal to the circumference of the cylinder, and the side A E equal to the length of cylinder. If we lay off along A E any convenient distance, A D, and draw the line D C parallel to A B,

we have the rectangle $A B C D$. Now draw the diagonal, $A C$, of this rectangle and wrap the paper around the cylinder, keeping the side $A E$ on an element of the cylinder; the paper will just cover the cylinder, the edge $B F$ meeting the edge $A E$. The point C coincides with point D , and is on the same element of the cylinder as A ; therefore the line $A C$ has made one complete turn around the cylinder, advancing the distance $A D$ in this turn. The curve which the line $A C$ now takes is called a helix, and the distance $A D$ is called the pitch of the helix.

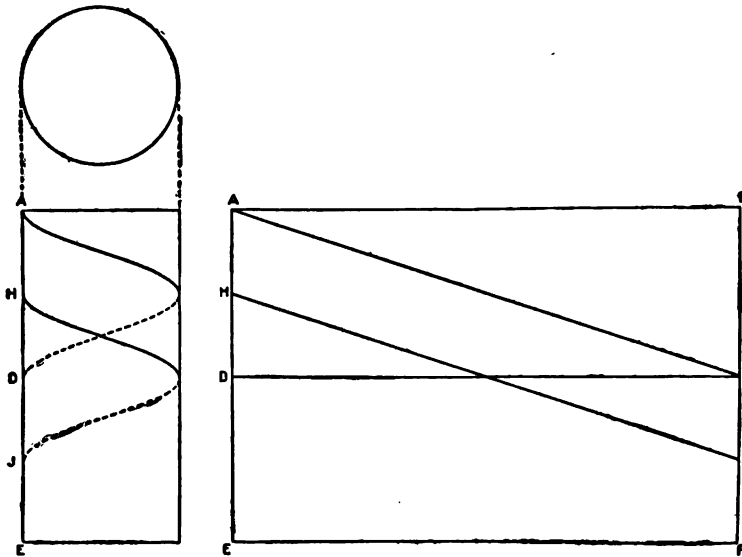


Fig. 1.

If on the piece of paper we also choose a point, H , halfway between A and D , and draw from this point a line, $H J$, parallel to line $A C$, this line $H J$ will form another helix parallel to the helix found by the line $A C$, when the paper is wrapped around the cylinder. The pitch of both helices is the same.

The helix is often incorrectly called a spiral, but there is a marked difference between the two; the spiral is a curve which lies in one plane, and winds around a point, constantly receding from the point, according to some law. The mainspring and hair-spring of a watch are in the form of spirals.

To draw the projections of a helix we must know the diameter of the cylinder about which the helix is wound, and the pitch of the helix. Fig. 2 shows the construction. Draw two projections of the cylinder A B D C; along any element, preferably one of the contour elements, A B or C D, lay off the pitch A E. Divide the circumference of the circle, which is the end view of the cylinder, into any number of equal parts, and number the points of division 1, 2, 3, etc. Divide the pitch A E into the same number of equal parts, and number these points of division in the same way that the points on the circle are numbered, calling

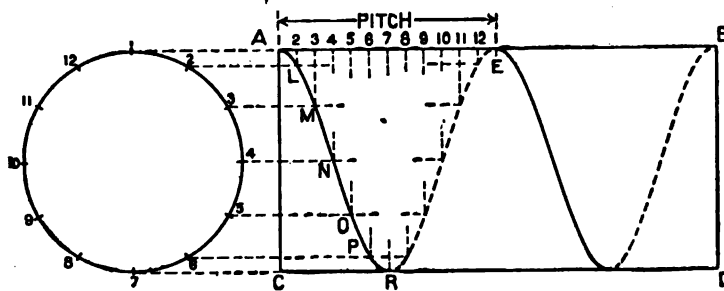


Fig. 2.

the point A No. 1. From point 2 on the circle draw a line parallel to A B, and from point 2 on A B draw a perpendicular to A B. The point, L, where the parallel line meets the perpendicular line, is one point on the projection of the helix. The points M, N, etc., are found in the same manner. A smooth curve starting from A, going through all the points and ending at E, will be the projection of one turn of the helix. The half from A to R is on the front, and is therefore a full line, while the half from R to E is on the back and is a dotted line. It should be observed that the point R is on the perpendicular from 7, which is just halfway between A and E, that is, the distance C R is just one-half the pitch. The curve from E to B is the projection of the next turn of the helix and is exactly like the first one.

The helix shown in Fig. 2 is called a right-handed helix. If the curve starts at C and is drawn as in Fig. 3, we have a left-handed helix. Notice that the visible part (from C to R) slants

in the same direction as the invisible part of the right-handed helix, which is shown dotted in Fig. 2.

Since the helix is a line drawn on the surface of a cylinder, the other projection of the helix must be the circumference of the circle, which is the end view of the cylinder. Fig. 4 shows a right-handed double helix, and Fig. 5 is a right-handed triple helix.

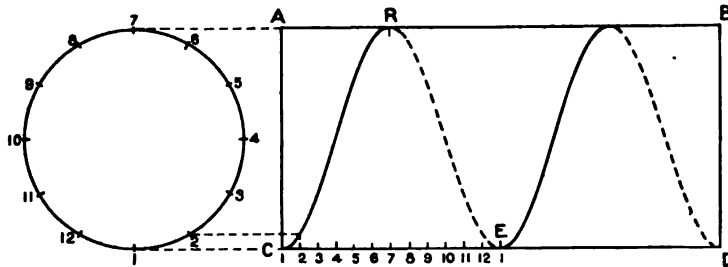


Fig. 3.

The construction of these curves should be studied carefully in order that the springs and screw threads may be better understood.

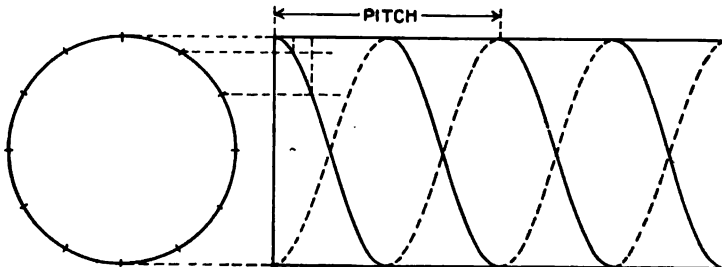


Fig. 4.

Helical Springs. If, instead of winding a line around a cylinder in the form of a helix, as shown in the preceding figures, we wind a piece of spring wire, we will get a helical spring.

Fig. 6 is the drawing of a helical spring of round wire, the side view only being drawn, as this is all that is necessary to give all the dimensions. To draw the spring we must know the pitch,

the diameter of the wire, and either one of the dimensions, A, B or C. If A is given, we subtract from A the diameter of the wire to find B; and if C is given, we add to C the diameter of the wire to get B; then knowing B and the pitch we can draw the helix (which is shown in dotted lines) exactly as the helix was drawn in Fig. 2. This is the helix formed by a line in the center of the wire. Now draw a series of circles with centers on this

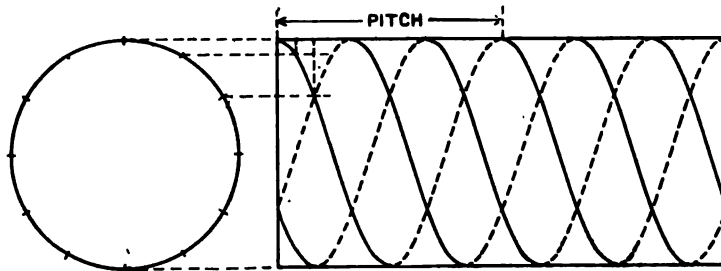


Fig. 5.

helix and of a diameter equal to the diameter of the wire. Smooth curves drawn tangent to these circles, as shown in the figure, will give the projection of the spring.

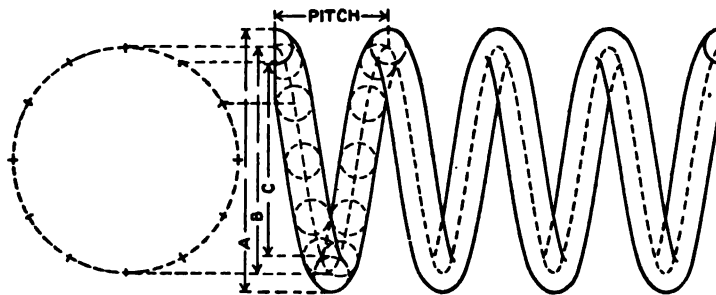


Fig. 6.

Fig. 7 shows a helical spring of square wire. The drawing of this is simply the drawing of four helices, starting from each of the corners of the square, A C M L; this square being the cross-section of the wire of which the spring is made. All four of the helices have the same pitch, equal to A B, for since the square

I E. The vertical lines drawn from the divisions of the pitch A B can be used for the divisions of L N, and those drawn from divisions of C D can be used for M P.

After the four parallel helices are drawn it is necessary to study the drawing carefully to decide what lines will be visible (full lines) and what invisible (dotted lines). Dotted lines should be used from H to J, N to P, etc., and full lines from F to G, B to D, etc. The line S T is the end of the spring, and consequently any part of a helix which goes outside of that line should not be left on the finished drawing. It is better, however, to draw in the whole of the square A C M L and to draw the helices starting from A and L in order to draw those parts of the same helices which lie to the right of S T. The parts to the left of S T are shown in the figure by light dotted lines to indicate that they are construction lines, and not a part of the projection of the spring itself.

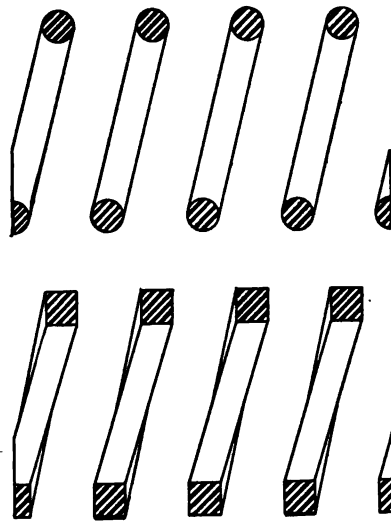


Fig. 10.

Conventional Representations of Springs. To draw springs by the method just explained involves considerable work and would consume

a great deal of time if many were to be drawn, therefore in working drawings the draftsman frequently uses a conventional method. This conventional drawing is similar to the true projection, except that straight lines are used in place of curved lines. Fig. 8 shows the conventional drawing of a spring of round wire, and Fig. 9 of a spring of square wire. Springs are often shown in half-section, as in Fig. 10, this method involving less work than the method of Figs. 8 and 9.

SCREW THREADS.

If we cut a groove around a cylinder in the form of a helix we shall have what is called a screw thread, the thread being

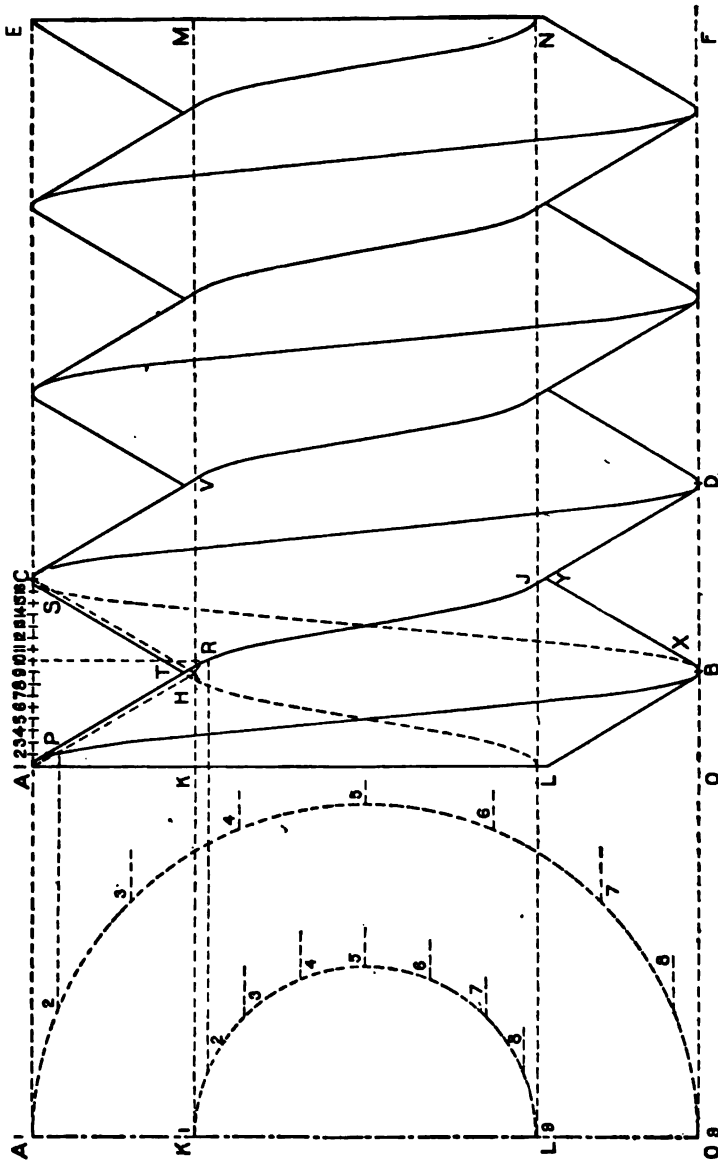
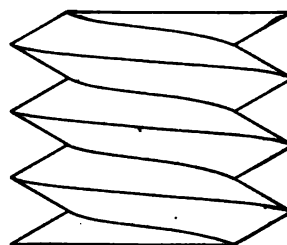


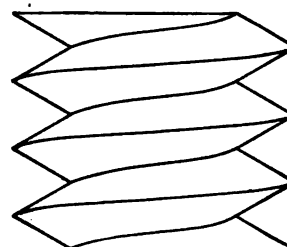
Fig. 12. Construction of V Thread.

formed by the material which is left between the successive turns of the helical groove. A cylinder having such a helical groove cut around it is called a screw, and a piece having a cylindrical hole in it with a helical groove cut around the hole is called a nut. The most common uses of the screw are to fasten pieces together or hold them at a given distance apart, and to cause one piece to move with relation to another piece.

V Thread. The form of screw thread with which we are most familiar is what is known as the V thread, shown in its simplest form in Fig. 11. Fig. 12 shows the method of drawing the true projections of this thread. The dimensions which must be known in order to make the drawing are the outside diameter, A O, the pitch, A C, and the depth of the thread, A K. First draw the two projections of a cylinder of a diameter equal to the outside diameter of the screw. Half of the end view is sufficient. On the line A E of this cylinder lay off A C equal to the pitch, and starting at A draw the helix A B C D, as described for Fig. 2. Inside of the cylinder A O, draw a smaller cylinder, K L, the diameter of which is equal to the diameter A O minus twice



LEFT-HAND THREAD.



RIGHT-HAND THREAD.

Fig. 11.

the depth of the thread. Now on this smaller cylinder, starting at point H, perpendicularly under a point on the line A C which is halfway from A to C, draw the helix H J V with the same pitch as was used for the helix A B C. Draw the lines P R, X Y, S T, etc., tangent to the two helices, and the projection of the thread is completed. It is necessary to draw the invisible parts of the two helices in order to draw the lines S T, X Y, etc., but they need not be left on the finished drawing. In Fig. 12 they are shown dotted for one turn of the screw in order to show the construction.

Fig. 13 shows the method of drawing a double V thread.

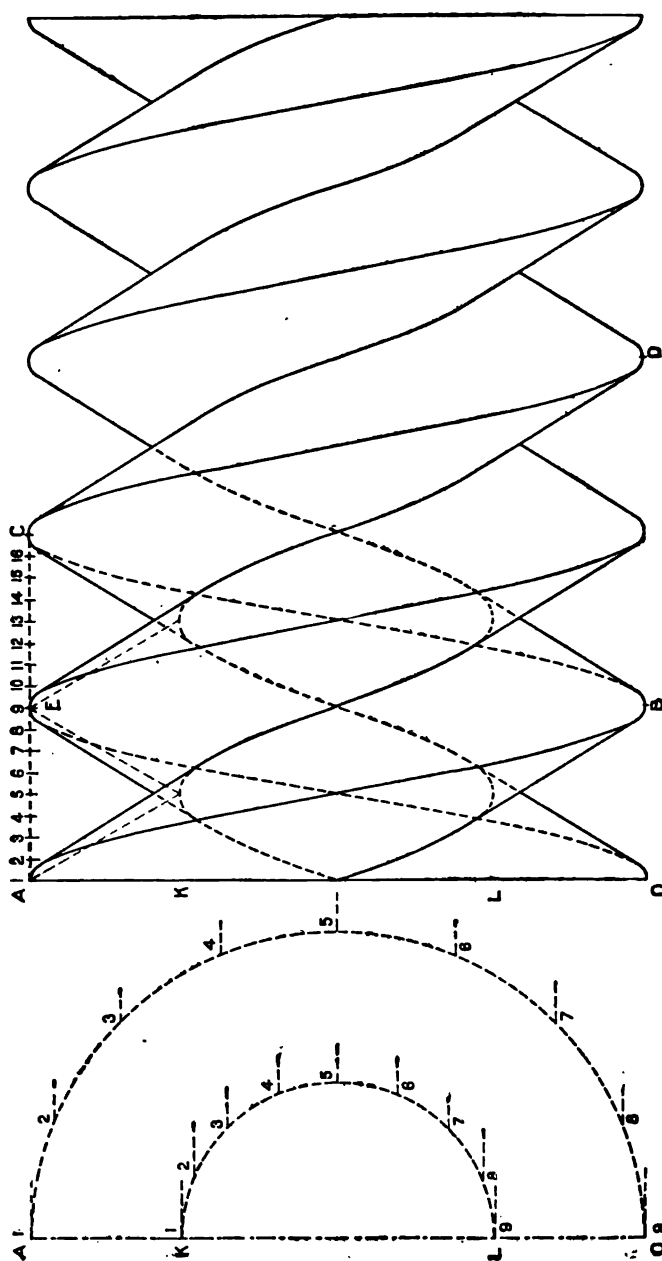


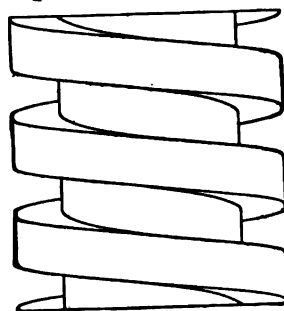
Fig. 13. Construction of Double V Thread.

The process is exactly the same as for drawing a single thread. Start at point A and draw the single thread A B C D exactly as in Fig. 12; then start at point E, halfway between A and C, and draw another single thread of the same pitch as the first one. Some thought may be necessary to decide when the lines of one thread become hidden behind the other thread.

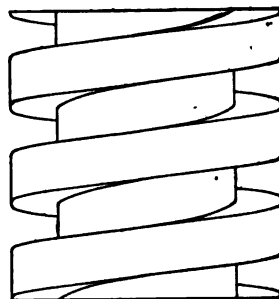
Square Thread. Another very common form of screw thread is that shown in Fig. 14, and is known as the square thread. The method of drawing this thread is similar to that for the V thread with the exception of a few minor points. The construction is shown in Fig. 15. The dimensions which must be known are the outside diameter, A O, the pitch, A C, the depth, A H, and either the width of the thread, A R, or the width of the groove, R C. In the figure, the width of the thread, A R, is taken equal to one-half of the pitch, that is, A R and R C are equal. Beginning at A, draw the helix A B C, and beginning at R draw the helix R M N, R N of course being equal to A C. Since

the part between A and R is metal, forming the thread, there will be a line from A to R and from B to M, etc. Now, starting at point H vertically under A and at a distance from A equal to the depth of the thread, draw the helix H J V, and from S vertically under R draw helix S T W. Draw the lines S V, T N, etc. Here, as in the case of the V thread, the invisible lines must be drawn when making the drawing; but need not be inked.

Fig. 16 shows the construction of a double square thread. An explanation is not necessary, since the difference between this



LEFT-HAND THREAD.



RIGHT-HAND THREAD.

Fig. 14.

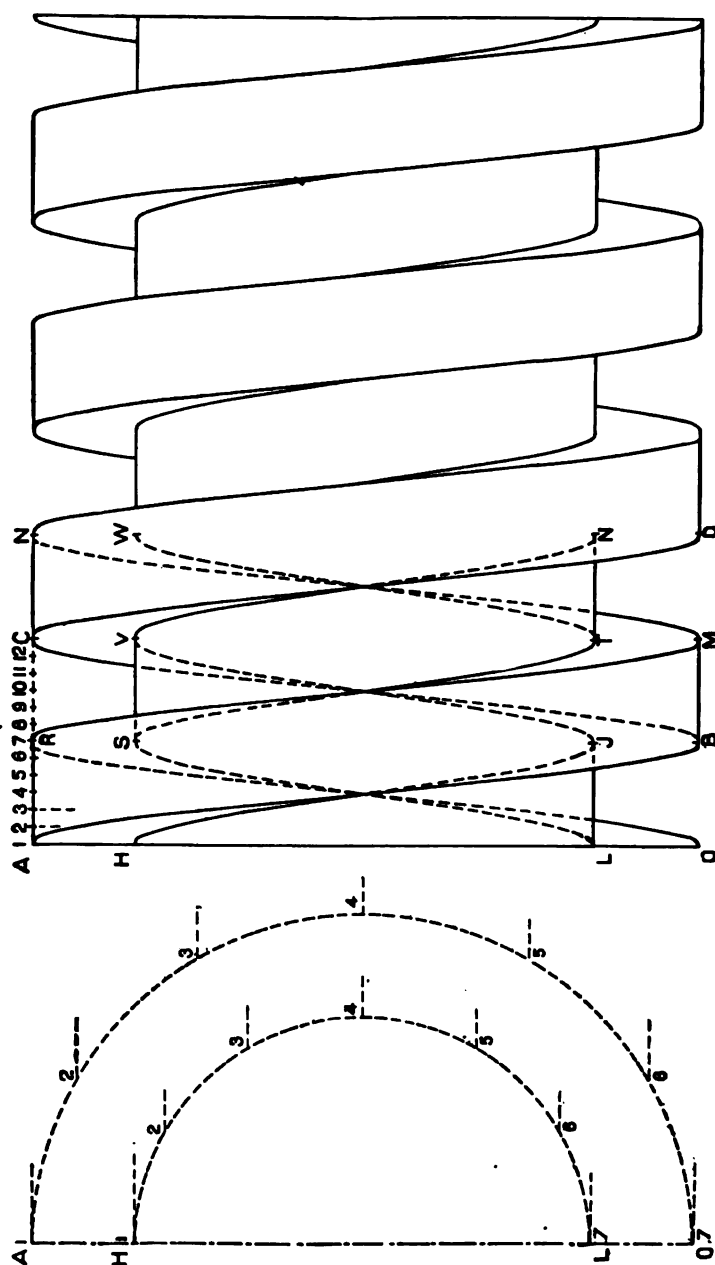


Fig. 15. Construction of Square Thread.

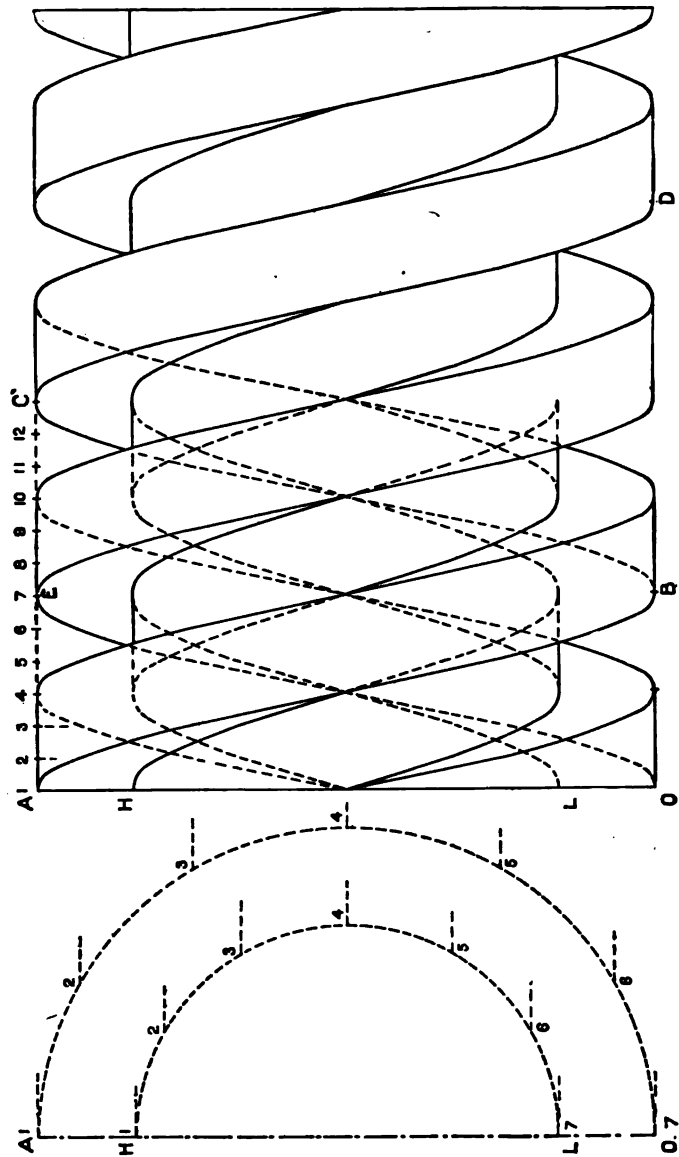
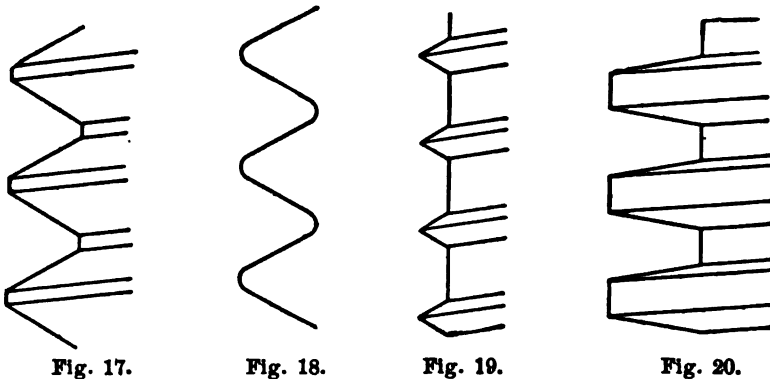


Fig. 16. Construction of Double Square Thread.

and the single square thread is practically the same as between the single and double V thread.

The V and square threads are the two fundamental forms of threads in use and all other forms are modifications of one or the other of these two. Figs. 17 to 20 show some of the more common modifications.

Figs. 17 and 18 show the two forms of the V thread which are commonly used in practice.



In Fig. 17 we have what is known as the Sellers or United States standard thread, an enlarged drawing of which is shown in Fig. 21. Referring to this figure, we see that the angle between the two sides of the thread is 60 degrees, so that if the thread came to a point at the top and bottom, as indicated by the dotted lines, the depth of the thread, D , would be about $\frac{3}{10}$ of the pitch, P . The sharp corners, however, are a disadvantage, since on the outside they are likely to be bruised, and give trouble in putting on the nut, and at the bottom of the groove they tend to weaken the bolt or screw. In order to avoid these sharp corners, the threads are flattened in the United States standard thread, as shown in Fig. 21, the amount of this flattening being such that the distance C is $\frac{1}{8}$ of the pitch, or, what amounts to the same thing, the distance A is $\frac{1}{8}$ of D . This gives a thread whose depth, E is $\frac{6}{10}$ of the pitch.

Fig. 18 illustrates what is known as the Whitworth standard thread, shown enlarged in Fig. 22. Here the angle between the

sides of the thread is 55 degrees, so that if the threads came to sharp corners, as shown by the dotted lines, the depth D would be $\frac{96}{1000}$ of the pitch. The top and bottom of the thread, instead of being flattened, are rounded off so that the distance A is $\frac{1}{8}$ of D , or the depth E is $\frac{64}{1000}$ of the pitch.

Fig. 19 shows the V thread as used on lag screws and other wood screws. Here the groove is much larger than the thread,

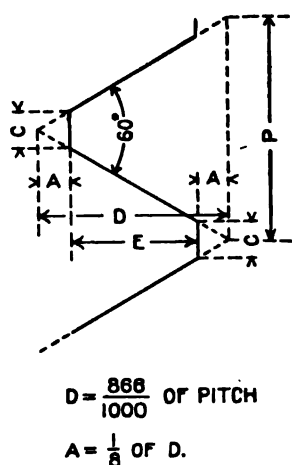


Fig. 21.

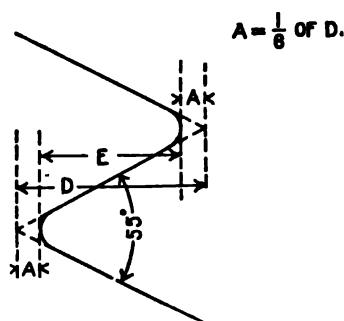


Fig. 22.

because the wood into which it is to screw is weaker than the iron of which the screw is made.

Fig. 20 shows a slightly modified form of square thread, the only difference between this and the square thread previously described being that the sides of the groove taper slightly.

Conventional Representations. The student should understand the drawing of the threads, as previously explained, and every draftsman should be able to draw the true projection of a thread if he should have occasion to do so. It is evident, however, that the process is somewhat long, and on a screw of small diameter and pitch it would be difficult to follow out the construction. To avoid this labor the construction shown in Figs. 23, 24 and 25 may be adopted, straight lines being substituted for the projections of the helix. Fig. 23 shows the conventional

representation of the plain single right-hand V thread, the true projection of which was shown in Fig. 12. To make the conventional drawing (Fig. 23) draw the parallel lines A B and C D at a distance apart equal to the outside diameter of the screw, and draw the line A C perpendicular to these two lines. Along A lay off the distances A E, E F, etc., each equal to the pitch. Along C D lay off C H equal to $\frac{1}{2}$ the pitch, and from H lay off H I, I J, etc., equal to the pitch. Draw lines from A to H, E to I, etc. Now, if the depth of the thread A S is known, draw the lines S T and U V, and beginning at L, perpendicularly under a

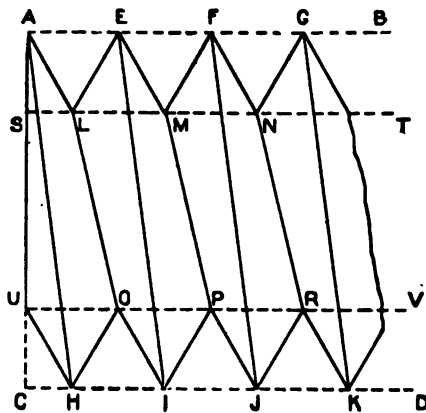


Fig. 23.

point halfway between A and E lay off L M, M N, etc., equal to the pitch. In like manner find the points O, P, R, etc., and draw the lines L O, M P, etc.; also A L, L E, H V, H O, etc. The dotted lines should be left out in the finished drawing, but are put in the figure to show the construction.

If, instead of knowing the depth A S, we know

the angle between A L and L E, the depth can be found by drawing from A and E the two lines A L and E L in such a way that they would make the required angle with each other. To do this the lines A L and E L would each make an angle with the line A B equal to 90 degrees minus $\frac{1}{2}$ the angle between A L and L E.

Fig. 24 shows the corresponding construction for the United States standard thread. Draw the lines A B, C D and A C as in Fig. 23, and find the points E, F, G, H, I, J, K, etc., in the same way as in that case. Now draw the lines S T and U V so that A S and C U shall equal $\frac{6.5}{100}$ of the pitch A E. On the line A B lay off from A a distance, A 1, equal to $\frac{1}{16}$ of the pitch, and each side of E, F, G, H, etc., lay off E 2, E 3, etc., each equal to $\frac{1}{16}$ of the pitch. From the points thus found draw lines 1-4, 2-5, etc.,

making an angle of 60 degrees with A B. The rest of the drawing is completed as shown by drawing in full lines those parts of the lines A B, C D, S T and U V intercepted between 1-4 and 2-5, etc.

Fig. 25 shows the conventional representation of a square thread, and is drawn in exactly the same way as the true projection shown in Fig. 15, except that straight lines are used instead of curves.

Square threads are almost always represented as in Fig. 25, and V threads of coarse pitch and large diameter are shown as in Fig. 23 or 24, but

when we have a screw of small diameter and fine pitch, such a method would become difficult, so that we most frequently find V threads represented as in Fig. 26. The lines A B and C D are drawn full, their distance apart being equal to the outside

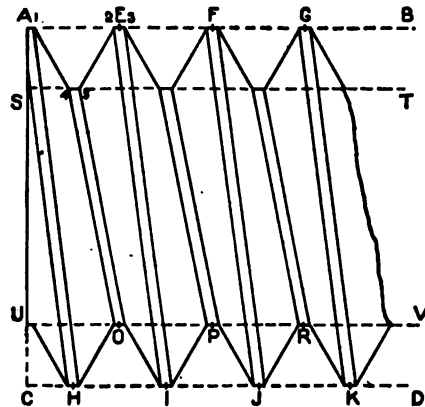


Fig. 24.

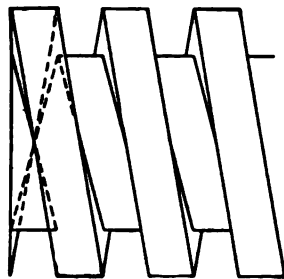


Fig. 25.

diameter of the screw. A F, F H, etc., are laid off to represent the pitch (though in small screws it is frequently made larger than the actual pitch). For a single thread, C E is equal to $\frac{1}{2}$ of A F, or, in other words, E is perpendicularly opposite a point halfway between A and F. A E is drawn, and F G, H J, etc., drawn parallel to A E. Halfway between the lines A E and F G, the shorter

and heavier lines are drawn, the distance from A B and C D to the ends of the heavy lines being a little less than A F. To have these lines of uniform length it is well to draw light pencil lines, as a guide for stopping the heavy lines, these guide lines being erased when the drawing is finished.

Fig. 27 shows the same method of representing a double

thread. The only difference between this and Fig. 26 is that in Fig. 27 C E is equal to A F; that is, E is perpendicularly opposite F.

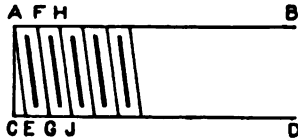


Fig. 26.

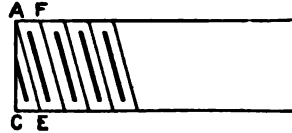


Fig. 27.

CAMS.

A cam is a piece of mechanism which, by means of its rotation about a fixed axis, imparts a back and forth motion to another piece in contact with it. There are several forms of cams which we shall consider, but before beginning the study of the cams and how to draw them it will be necessary for us to understand something of the different kinds of motion a piece may have, because a cam must be designed to give the piece the kind of motion desired.

Kinds of Motion. If we classify the kinds of motion which we meet with in machinery according to the rate of motion, or velocity, the three most common kinds are *uniform motion*, *harmonic motion* and *uniformly accelerated and uniformly retarded motion*. These will be more readily understood after we have considered one or two illustrations.

Uniform Motion. Suppose a railway train to travel ten miles in twenty minutes, the speed of the train being the same during each minute; it would travel $\frac{1}{2}$ mile in each minute, and would be said to have a *uniform* speed, or *uniform* velocity of $\frac{1}{2}$ mile per minute. Under such conditions the train would be moving at the full speed of $\frac{1}{2}$ mile per minute both at the beginning and at the end of the ten miles. If, however, it had exactly ten miles to travel and exactly twenty minutes to do it in, and must be at full stop at the beginning and at the end of the given time, it could not take up its full speed in an instant nor lose it in an instant, but must start gradually and stop gradually, and therefore during the first part and the last part of the time would be moving at a speed slower than $\frac{1}{2}$ mile per minute, and must go faster than $\frac{1}{2}$ mile per minute during the middle part of the run to make up for

the time lost in starting or stopping, or, in other words, the motion would not be uniform. The more suddenly the train starts and stops, the more nearly uniform the motion may be, but the greater the shock when starting and stopping. Let us take another example on a smaller scale. Suppose we have some sort of a piece to be moved one foot across a machine in ten seconds; if the motion is to be uniform, the piece would have a velocity of $\frac{1}{10}$ foot per second. If the piece is light and the mechanism which does the moving is sufficiently powerful, the piece may be made to start and stop almost instantly and consequently may have what is practically uniform motion. It is evident, however, that the shock at starting and at stopping would be considerable.

Varying Motion. If the mechanism which moves the piece is so designed as to start and stop it gradually, the shock will be avoided. The character of this gradual increase and decrease of speed might be one of several kinds, but what would most likely be met in practice would be either a gradual increase of speed at the start, until full speed is attained, then a uniform full speed during the main part of the stroke, and finally a gradual decrease of speed to a full stop at the end of the stroke; or the speed would increase during the entire first half of the stroke, and decrease during the entire last half, the motion at no time being uniform. The first condition is most likely to be used where the piece is doing work during the stroke, as, for instance, the cutting stroke of a tool, and the second condition is used where it is desired to get the piece across quickly without regard to the character of the motion as long as it is without shock. The character of the motion usually employed in this case is either what is known as *harmonic motion* or *uniformly accelerated and retarded motion*, and we will now study these.

Harmonic Motion. In Fig. 28 let the semicircle A B D represent the path along which a piece moves with a uniform velocity. Now, if we have another piece moving along the diameter A D, starting from A at the same time that the first piece does, and moving at such a speed that a perpendicular let fall from any position of the first piece to the line A D will strike where the second piece is,—that is, when the first piece is at C the second piece is at E; when the first piece is at B the second piece is at O,

and so on,—then the piece which travels across the line A D is said to have *harmonic* motion, and it is evident that it moves slowly at first, increases to a maximum speed at the center, and decreases towards the end.

Uniformly Accelerated and Retarded Motion. A piece which has uniformly accelerated and uniformly retarded motion travels at such a speed that it will move through one unit of space in the first unit of time, three the second, five the third, seven the fourth, nine the fifth, etc., to the middle of its stroke, then decreases at the same rate to the end of the stroke. For example, if a piece is to move with uniformly accelerated and retarded motion one foot in ten seconds, it will move $\frac{1}{10}$ foot the first second, $\frac{3}{10}$ the

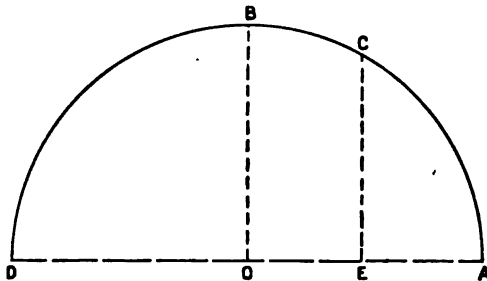


Fig. 28.

second, $\frac{5}{10}$ the third, $\frac{7}{10}$ the fourth, $\frac{9}{10}$ the fifth, when it will have traveled $\frac{1}{10} + \frac{3}{10} + \frac{5}{10} + \frac{7}{10} + \frac{9}{10} = \frac{25}{10}$ or $\frac{5}{2}$ the whole foot in five seconds, or $\frac{1}{2}$ the whole time, the speed increasing all the time; at the end of the fifth second,

or in other words, when half the distance has been traveled, it begins to slow down, and travels $\frac{9}{10}$ the sixth second, $\frac{7}{10}$ the seventh, $\frac{5}{10}$ the eighth, $\frac{3}{10}$ the ninth, and $\frac{1}{10}$ the tenth. The rate at which the velocity increases during the first half of the time is the same as that at which the velocity of a weight will increase if dropped from a height, and the rate at which the velocity decreases during the last half of the time is the same as that at which the velocity of a ball will decrease if thrown straight up into the air. The uniformly accelerated and retarded motion is therefore often spoken of as *gravity* motion.

One of the most common means of obtaining the kinds of motion just described is by cams, although these are not often used for motions greater than a few inches.

Kinds of Cams. Cams may be divided into two general classes, *plate cams* and *cylindrical cams*. Either one of these may be designed for uniform motion, for harmonic motion, for

gravity motion, or for a combination of two or even of all three.

Plate Cams. Fig. 29 shows the front and side views of a plate cam designed to raise the sliding piece P a distance A e; the lowest position of P being when its point is at A, and the highest position being when its point is at e, as indicated by the dotted lines. The cam turns right-handed, as shown by the arrow, and raises P with uniform motion from A to e while turning through

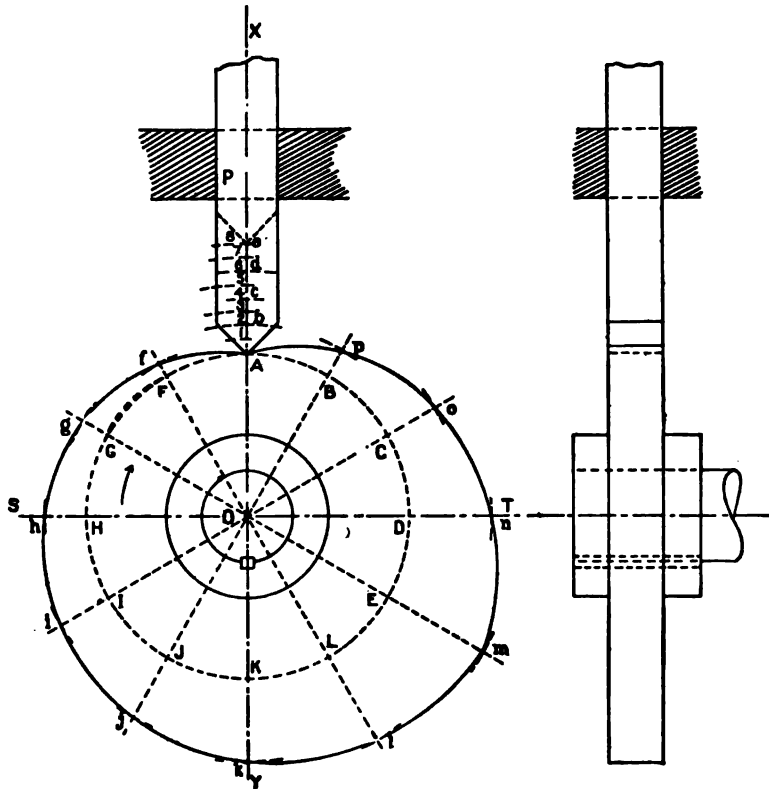


Fig. 29.

$\frac{2}{3}$ of a revolution, then lowers P with uniform motion to its original position while turning through the remaining $\frac{1}{3}$ revolution.

To design such a cam, start with the point O (the center of the shaft on which the cam is fixed); through O draw the center line X Y, and locate point A by measuring up from O the distance O A, which must be known; from A lay off A e, which must

also be known; with O as a center and radius $O A$ draw the circle $A H K D$; on this circle find a point E such that arc $A H E$ shall be to arc $A C E$ as the time allowed to raise P is to the time allowed to lower P . In this case, since P is to rise in $\frac{2}{3}$ of a revolution of the cam, and fall in $\frac{1}{3}$ of a revolution, the time allowed for it to rise is twice the time allowed for it to fall, and therefore the arc $A H E$ is twice the arc $A C E$, or, in other words, the arc $A H E$ is $\frac{2}{3}$ of the whole circumference, and $A C E$ is $\frac{1}{3}$ of the circumference. If the cam were to turn left-handed instead of right-handed, the arc $A C E$ would be $\frac{2}{3}$ of the circumference and $A H E$ $\frac{1}{3}$. Now since the motion is to be uniform, divide line $A e$ into any number of *equal* parts (eight are used in the figure) and divide the arc $A H E$ into the same number of equal parts; draw the radial lines $O F$, $O G$, etc., as shown; with O as a center and radius $O 1$ draw an arc cutting $O F$ at f ; with O as a center and radius $O 2$ cut $O G$ at g , and so on around to m . A smooth curve drawn through the points A, f, g, h , etc., around to m , will form the outline of that portion of the cam which raises P . Now it is evident that when the cam has turned through the angle $A O F$ the line $O F$ will coincide with the center line $X Y$, and the point f will coincide with point 1, and therefore the cam will have pushed the point of P from A to 1. In the same way, when the cam has turned through angle $A O G$, point g will coincide with 2, and when cam has made $\frac{2}{3}$ of a revolution m will coincide with 8 (which is the same as e), and P will have been raised the required amount.

The outline of the rest of the cam is found by dividing arc $A C E$ into any number of equal parts, and making a new division of $A e$ into the same number of equal parts (ed, dc , etc.). Points n, o and p are found in the same way as f, g , etc., and a smooth curve drawn through them.

Fig. 30 shows a plate cam similar to that shown in Fig. 29, except that in Fig. 30 the piece P is raised from A to e during $\frac{1}{2}$ a revolution of the cam, and lowered during the other $\frac{1}{2}$ revolution; that is, the time allowed for raising P is the same as the time allowed for lowering it. The motion is uniform in both raising and lowering. The method of drawing this cam is similar to that explained in Fig. 29, except that $\frac{1}{2}$ the circle $A H$

K D is divided into the same number of equal parts as the line A e instead of $\frac{2}{3}$ as before, k now being the point farthest from the center instead of m as in the previous case. This form of cam is called a *Heart Cam*.

Fig. 31 shows another cam, which is similar to that of Fig. 29. It will be noticed, however, that in Fig. 29 the line in

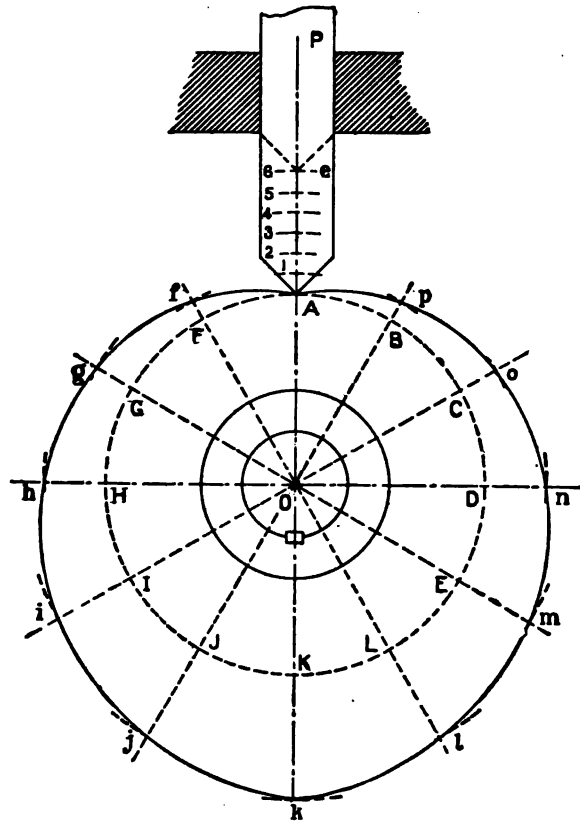


Fig. 30.

which A travels coincides with the center line, X Y, or, in other words, the line of motion of point A passes through the center of the cam. In Fig. 31 the path of A does not pass through the center of the cam, but lies in the line V W, which passes a distance R to one side of the center O. The cam shown in the figure is designed to raise P a distance A e in $\frac{2}{3}$ of a revolution,

and lower it in the remaining $\frac{1}{3}$, just as in Fig. 29, the motion being uniform. To design the cam, locate center O and draw the center lines X Y and S T at right angles with each other. On S T measure from O a distance equal to R, which must be known, thus getting the point *a*; through *a* draw V W parallel

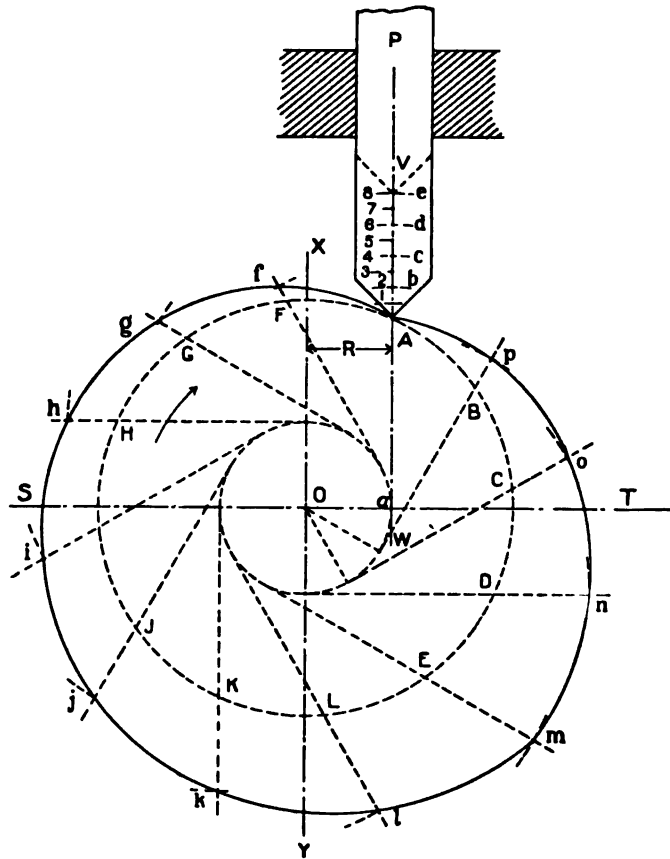


Fig. 31.

to X Y. Locate A and *e* on this line, the distances A *a* and A *e* being known. Through A draw a circle with O as a center; on this circle locate point E so that arc A H E shall be to arc A C E as time required to raise P is to time required to lower it; in this case as $\frac{2}{3}$ is to $\frac{1}{3}$, or, in other words, arc A H E is $\frac{2}{3}$ of the circumference. Divide A *e* into any number of equal parts, and divide

arc A H F into the same number of equal parts. With O as a center and radius O *a*, draw a circle tangent to V W, and through the points of division F, G, H, etc.; on the large circle draw lines tangent to the smaller circle. With O as a center draw an arc through point 1, cutting line through F at *f*; points *g*, *h*, etc., are found in the same way by drawing arcs through 2, 3, etc. A smooth curve drawn through these points around to *m* gives the outline of that part of the cam which raises the point of P from A to *e*. The curve through *n*, *o*, *p*, which lowers P, is found in the same way. It will be noticed that the only differ-

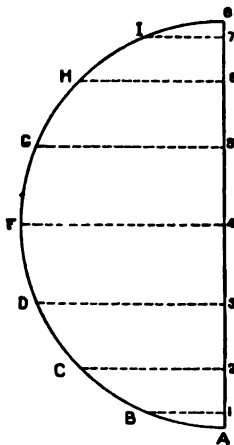


Fig. 32.

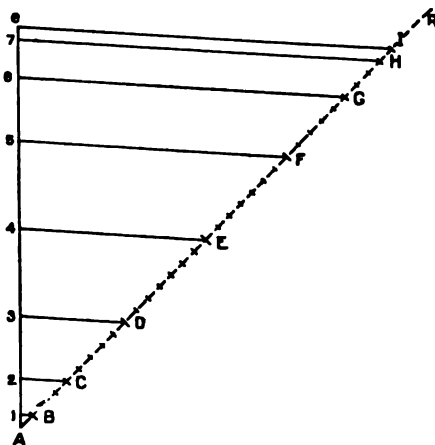


Fig. 33.

ence between the method of laying out this cam and that in Fig. 29 is that the lines on which points *f*, *g*, *h*, etc., are found are drawn tangent to the small circle instead of to the center. The hub and bore for shaft are omitted on this drawing to avoid confusing the lines.

If, in Fig. 29, it had been required to raise and lower P with harmonic motion instead of uniform motion, the only difference in construction would have been in the dividing up of the line A *e*. The divisions A F, F G, etc., on the circle, would be the same as for uniform motion; that is, they would be equal to each other. The divisions A-1, 1-2, etc., on line A *e*, instead of being equal would be found as shown in Fig. 32. On the line A *e* as a diam-

eter, draw a semicircle, and divide this semicircle into as many equal parts as we divide the arc A H E in Fig. 29. From the points B, C, D, etc. (Fig. 32), draw perpendiculars to line A e, cutting it at points 1, 2, 3, etc. These are the points which we would use for finding points *f*, *g*, *h*, etc., on the cam outline (Fig. 29). Fig. 32 is drawn to a larger scale than Fig. 29.

Fig. 33 shows how to divide the line A e, if the motion were to be uniformly accelerated and uniformly retarded. Since the line A e is to be divided into the same number of parts as the arc A H E, it will be divided into eight parts in this case. Now if the motion which the cam is to give to the piece P is to be uniformly accelerated and retarded, the line A e must be divided up in such a way that the distance from 1 to 2 is three times the distance from A to 1; the distance from 2 to 3 is five times the distance from A to 1; 3 to 4 is seven times A to 1; 4 to 5 is seven times A to 1; 5 to 6 is five times A to 1; 6 to 7 is three times A to 1; and 7 to e is equal to A to 1. Therefore the whole line A e is $1 + 3 + 5 + 7 + 7 + 5 + 3 + 1$, or thirty-two times the distance from A to 1, or, in other words, A-1 is $\frac{1}{32}$ of the whole line A e, 1-2 is $\frac{3}{32}$ of A e, and so on. To divide up A e so that the divisions may bear the above relation to each other, draw the line A R at any convenient angle, and choosing any convenient distance as a unit, mark it off on this line thirty-two times, beginning at A; from I, the last of these dividing points, draw a line to e; next find the points B, C, D, etc., as follows: B is the first division from A, C the third from B, D the fifth from C, E the seventh from D, F the seventh from E, G the fifth from F, H the third from G; through the points H, G, F, etc., draw lines parallel to I e, cutting line A e at 7, 6, 5, 4, etc.; then these points will be the required points of division for the line A e.

Fig. 34 shows a cam designed to raise P with uniformly accelerated and retarded motion, while the cam is turning right-handed through $\frac{1}{8}$ of a revolution; then P is to be held fixed in its raised position while the cam turns through the second $\frac{1}{8}$ revolution, and to be lowered with harmonic motion during the last $\frac{1}{8}$ revolution. The construction involves the methods already described. The arcs A F M, M N V and V E A are each $\frac{1}{8}$ of the

circumference. The dividing of the line $A e$ for uniformly accelerated and retarded motion is shown at the left of $A e$, giving points 1, 2, 3, etc., which are swung on to the lines $O G$, $O H$, etc., and thus locating points g , h , etc., as in the previous cams.

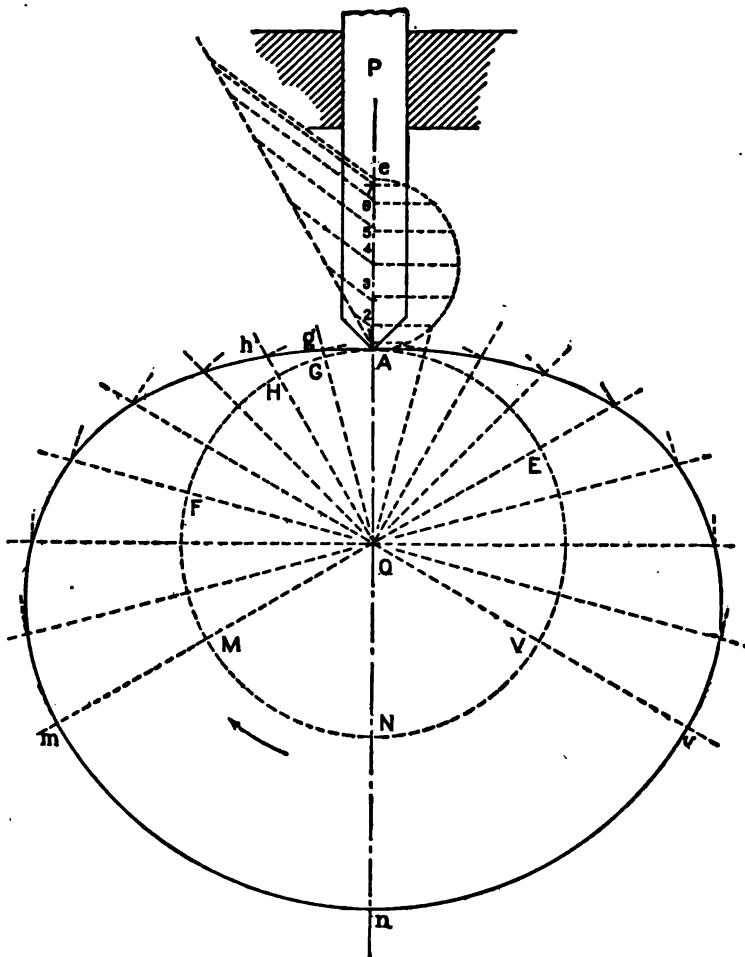


Fig. 34.

When the cam has turned through the angle $A O M$, the line $O m$ coincides with line $O e$, point m being at e , and the point of P will be raised to e . Now the point of P is to remain at e while the cam turns through the next $\frac{1}{2}$ revolution, that is, while it

turns through the angle $M O V$ and therefore that part of the outline of the cam from m to v is an arc of a circle drawn with O as a center. The dividing of $A e$ for the harmonic motion for lowering P is shown at the right of $A e$, and the points on the cam outline are found in the same way as before.

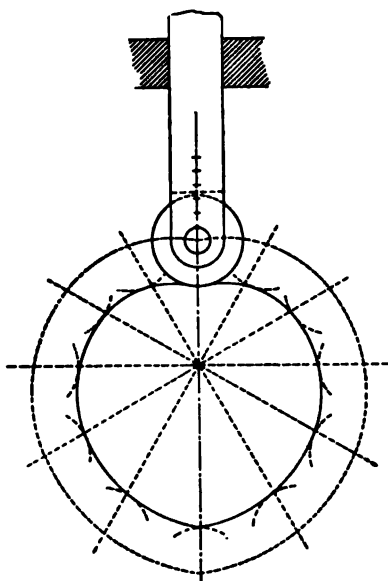


Fig. 35.

piece, as in Fig. 30, the center of the roller being at the place where the point of P is in Fig. 30. This curve is shown dotted in Fig. 35, and is exactly the same curve as the outline of the cam in Fig. 30. Now, with a radius equal to the radius of the roller which is to be used, and with centers at any number of points around the curve, draw arcs as shown. A smooth curve drawn *tangent* to these arcs will be the outline of the cam to act on the roller.

Cylindrical Cams.* A plate cam, as we have seen, can be designed to give almost any kind of motion in a plane at right angles to the axis of the shaft on which it is located, but cannot give motion in a line parallel to the axis of the shaft. If, however, we put a cylinder on the shaft with a groove cut in it, the

* The subject "Cylindrical Cams" is optional.

The cams which we have been considering all act on the comparatively sharp end of the piece P , and it is evident that, as the cam turns, its surface must slide on P , causing friction and rapid wearing. If, however, the end of P is provided with a roller which bears on the surface of the cam, the sliding and consequent wearing are avoided. Fig. 35 illustrates this, and shows how to lay out the cam. The cam here shown is to give the same kind and amount of motion to the follower P as the cam shown in Fig. 30. We first find the curve for the cam outline, if it acted on a pointed

shape of the groove may be made such as to give to a piece inserted in it almost any desired motion in a line parallel to the axis of the shaft. Such a cam is called a cylindrical cam, and is shown in Fig. 36, which, together with Figs. 37 and 38, shows the method of designing. This cam is designed to turn in the direction indicated by the arrow, and in so doing is to move a roller a distance A to the right with harmonic motion while turning $\frac{1}{4}$ revolution, to allow the roller to remain stationary during the next $\frac{1}{4}$ revolution, to move it back to its original position with uniformly accelerated and retarded motion during the third $\frac{1}{4}$

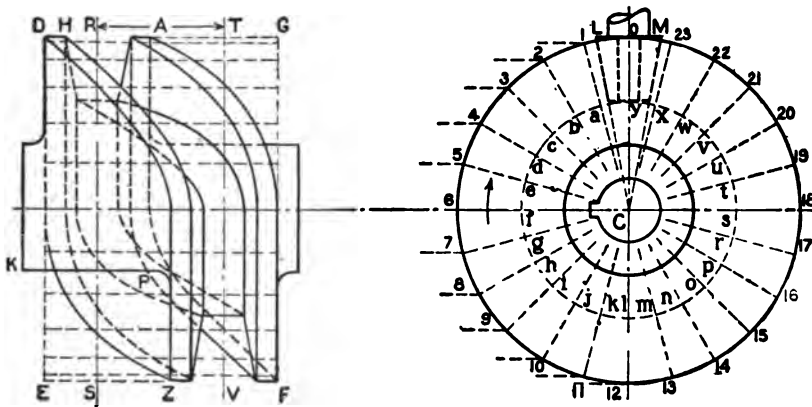


Fig. 36.

revolution, and to keep it stationary during the last $\frac{1}{4}$ revolution.

The roller is shown in the end view of the cam, and is of a diameter $L M$ at its outer end, and of a length $O O'$; it is made tapering, being the frustum of a cone whose apex is at the center of the cam. The depth of the groove is made exactly equal to the length of the roller, $O O'$, and the width of the groove is made equal to the diameter of the roller. The arrangement might be a little different in practice, but this will show the method of designing.

The length of the cylinder which forms the cam is $D G$, which is equal to A (the distance between the two extreme positions of the center of the roller) plus twice the radius of the

roller, plus twice D H (the thickness of metal allowed between the groove and the outside). In the figure the hub is allowed to project a little at each end.

To lay out the cam: Draw the two views of the cylinder, the side view being the rectangle D E F G, and the end view being the circle 0-6-18. We will start with the point 0. Since the roller is to move through distance A while the cam turns $\frac{1}{4}$ revolution, we lay off from 0 the arc 0-3-6 equal to $\frac{1}{4}$ the circumference; and the groove in this part of the cylinder must be such that when the cam has turned in the direction shown by the arrow until point 6 coincides with 0, the axis of the roller will have moved along in harmonic motion from a position coincident with center line R S (side view) to a position coincident with center line T V. The axis of the roller is to remain coincident with T V during the next $\frac{1}{4}$ revolution of the cam, that is, until point 12 comes to 0, and consequently the groove in this part of the cam goes straight around, the projection of its center line coinciding with T V. The roller is to be moved back until its axis coincides with R S with uniformly accelerated and retarded motion, while the next $\frac{1}{4}$ revolution is made, or until point 18 comes to 0, and the groove in this $\frac{1}{4}$ of the cam must be made such as will give that motion. The groove in the remaining $\frac{1}{4}$ of the circumference is again to be such as to keep the axis of the roller stationary, or, in other words, is to have the projection of its center line coincident with R S.

Now, in order to draw the projection of the groove in the side view, it will be necessary to make a development of the surface of the cylinder, using the same principles that were involved in the development of cylinders in Part III. Fig. 37 shows the development, and we will now consider in detail the method of making and using it. In Fig. 36 divide each of the arcs 0-6, 6-12, 12-18, 18-0 into any number of equal parts. In making the division it is more convenient to make the spaces into which these arcs are divided equal for all the arcs—that is, 1-2, etc. = 6-7, etc. = 12-13, etc. = 18-19, etc. On the side view of the cylinder (same figure) draw the elements corresponding to those points of division. Next draw the rectangle D E D' G' F G (Fig. 37), the length of the side D E D' being equal to the cir-

cumference of the circle 0-6-18 (Fig. 36), and the length of the side G D being the same as the line G D in Fig. 36. On

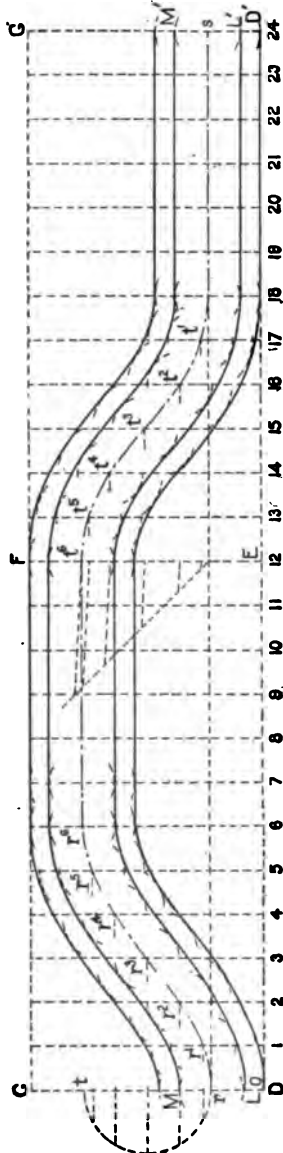


Fig. 37.

D E D' locate points 6, 12, 18, by making distances D-6, 6-12, 12-18, 18-D' equal respectively to arcs 0-6, 6-12, 12-18, 18-0, in Fig. 36. Divide each of the distances D-6, 6-12, etc., into the same number of equal parts as there are divisions in the corresponding arcs in Fig. 36, and at these points of division, which are numbered 1, 2, 3, etc., to correspond with the points in Fig. 36, erect perpendiculars as shown. On D G (Fig. 37) locate point r , making D r equal to the distance from D to line R S (Fig. 36), and draw line $r s$ parallel to D D'.

From r lay off $r t$ equal to A, and divide $r t$ for harmonic motion as shown, making the number of divisions the same as those between D and 6. From the first point of division project across to the perpendicular which was erected at 1, from the second point of division to the perpendicular which was erected at 2, etc., thus getting the points r^1, r^2, r^3, r^4 , etc., to r^6 . Through these points draw a smooth curve, as shown in dot and dash. The perpendicular distance from any point on this line, as r^3 , to the line $r s$, represents the distance that the axis of the roller has moved to the right of the center line R S, while the cam has turned

through the angle corresponding [through angle 0 C 3 (Fig. 36), if we consider the point r^3]. Since that part of the

circumference of the cylinder corresponding to a length of arc equal to line 6-12 is to have a groove that will hold the roller stationary, the line $r^6 t^6$ is a straight line parallel to $r s$. Divide the distance from t^6 to $r s$ for uniformly accelerated and retarded motion, and find points t^5, t^4 , etc., in similar way as we found r^1, r^2 , etc., and draw the curve through them. The line which we now have is the development of the center line of the groove. With a radius equal to the radius of the roller, and with centers at any number of points along the curve which has just been found, draw arcs as shown, and draw smooth curves tangent to these arcs, thus getting the curves $L L'$ and $M M'$, which are the developments of the sides of the groove. Now with the dividers take the distance from the line $r s$ to where the curve $M M'$ in-

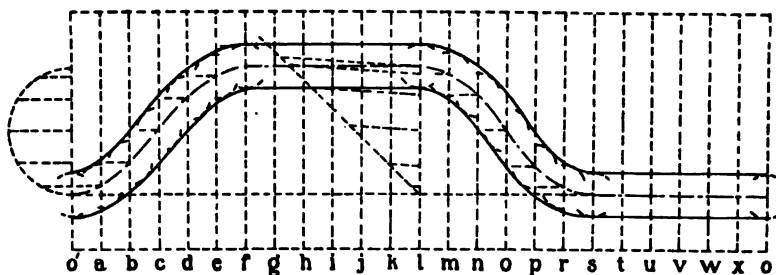


Fig. 38.

tersects the line $D G$, and lay this distance off from line $R S$ along line $D G$ of Fig. 36; in like manner take the distance from $r s$ to where curve $M M'$ intersects perpendicular at point 1, and lay this off from $R S$ along the element which corresponds to point 1 in Fig. 36. Do the same for the points where $M M'$ intersects at 2, 3, etc., and also for points where $L L'$ intersects these perpendiculars; distances above $r s$ being measured to the right of $R S$, and distances below $r s$ to the left of $R S$. We thus obtain two series of points on the side view of the cylinder in Fig. 36, and smooth curves drawn through these points give the projections of the edges of the groove on the surface of the cylinder.

To get the projections of the bottom corners of the groove, we must make a similar development of a cylinder whose length is the same as the one which we have just developed, but whose

diameter is the diameter of the larger one less twice the depth of the groove shown by the dotted circle in the end view of Fig. 36. The development is shown in Fig. 38, and is done in a manner exactly similar to that employed in Fig. 37. The method of getting the corresponding curves in the side view of Fig. 36 is also the same as for the curves on the outer cylinder.

We would now have a cam which would appear as in Fig. 39; but it is evident that there is a good deal of unnecessary metal, so that instead of making it a complete cylinder, the stock is usually cut away, as shown by the outer curves in Fig. 36, so that the distance from the center of the groove to the outside of the metal is everywhere equal to the distance from D to line R S. The projections of these outer edges of the metal are found by first making the development in Fig. 37, obtaining the upper and lower of the curves by striking arcs from the center curve with a radius equal to distance from D to R S (Fig. 36), and drawing the curves tangent to these arcs. The curves are transferred to the side view of Fig. 36 in the same way that the rest of the curves were. The hub is now drawn, extending as far beyond the rest of the cam as is desired, the contour of the hub (as K P) being visible to a point perpendicularly opposite where the outside edge of the cam strikes the contour of the cam (point Z for line K P).

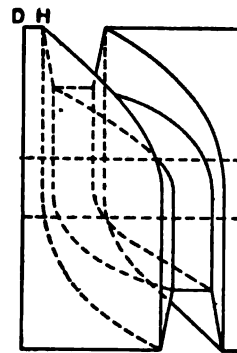


Fig. 39.

BELTING.

The word shaft, in connection with machinery, is a name applied to a bar, either hollow or solid, usually of circular cross-section (in common language, round), supported in suitable bearings so as to be free to turn, and intended to receive a motion of rotation from some source of power, and to transmit the motion to some other body, either another shaft or some piece of machinery. The number of times a shaft turns in a unit of time is

called the speed of the shaft, and is usually stated as number of turns in a minute, or revolutions per minute, which is abbreviated to R. P. M.; this abbreviation will be used in what is to follow. When it is desired to drive one shaft from another at some distance from it, the connection is commonly made by placing on each shaft a pulley or wheel, and over these pulleys stretching a band or belt, as it is called, made of leather, rubber, canvas or some similar material. The pulleys are fastened to the shaft, so that a shaft and its pulley turn together, and the belt is stretched over the pulleys tight enough so that the friction be-

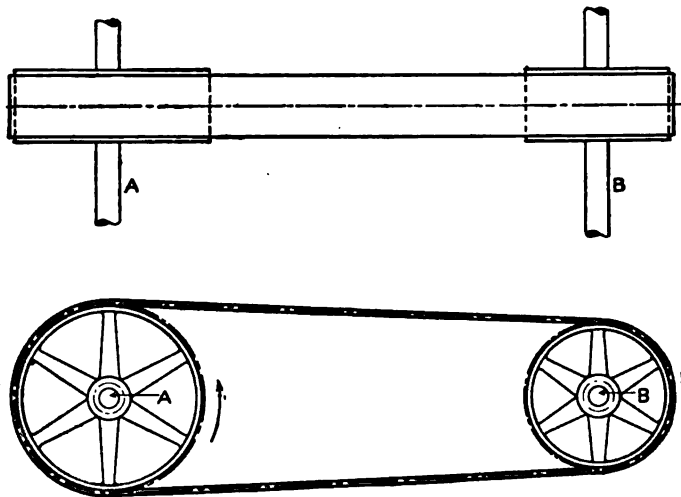


Fig. 40.

tween the belt and the surface of the pulleys is sufficient to make the linear speed of the belt practically the same as the linear speed of the circumference of the pulleys. The shafts which are connected by a belt may be parallel or nonparallel.

The methods of laying out the locations of pulleys and belts for the various cases which are commonly met with will now be considered. Before doing this, however, it will be necessary to consider a few general definitions and a few of the principles which govern belting.

Fig. 40 is an elevation and a plan of two shafts, A and B, which are connected by a belt. The *pitch line* of the belt is an

imaginary line exactly in the center of the belt, both as regards thickness and width. The pitch line of each pulley is a circle drawn around the center of the pulley, with a radius equal to the radius of the pulley plus one-half the thickness of the belt. The pitch line of the pulley, therefore, coincides with the pitch line of that portion of the belt which is in contact with the pulley. The pitch lines of both the belt and the pulleys are shown in the figure by dot and dash lines. The diameter of this pitch circle of the pulley is called the effective diameter of the pulley, and should be used in place of the real diameter in all calculations and drawings for the location of pulleys, if such calculations

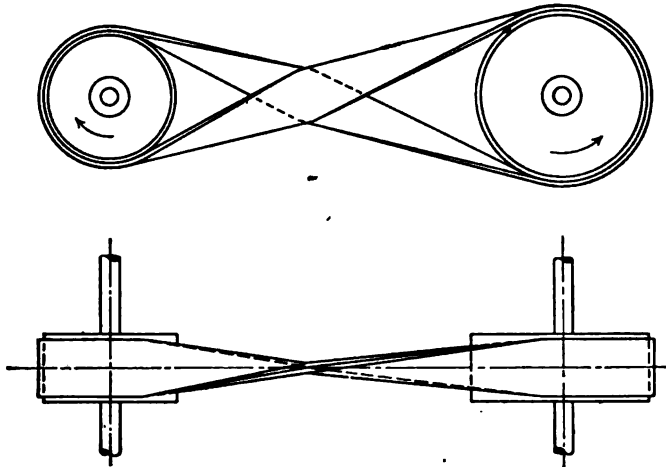


Fig. 41.

and drawings are required to be absolutely accurate. The thickness of the belt, however, is almost always small compared with the diameter of the pulley, so that the error introduced by neglecting to make allowance for this thickness is so small as to be almost unnoticeable. It is generally safe to use the real diameter of the pulley instead of the diameter of its pitch circle, and this will be done in our discussion of the subject.

Parallel Shafts. Open and Crossed Belts. The belt shown in Fig. 40 is what is known as an open belt, and two shafts connected by such a belt will both revolve in the same direction. Fig. 41 shows a crossed belt, which causes the driven shaft to

turn in the opposite direction from the driving shaft. The shafts in Fig. 40 and Fig. 41 are parallel to each other.

Shafts not Parallel. It very often happens that two shafts which are not parallel are to be connected by a belt, and this can always be done, whatever the position of the shafts with relation to each other, provided the pulleys are so located as to conform to one fundamental principle which governs the running of all belts. This principle may be stated as follows: The point where the center line of a belt leaves a pulley must lie in the plane which contains the pitch line of the pulley which receives the belt. Another way of stating this principle is: The center of a belt must be delivered into the center plane of the pulley to which it is running. This law is of great importance, as it applies to belts however they are bent or twisted, and the student should understand it clearly and have it fixed firmly in mind. From the study of geometry we learn that a plane is a perfectly flat surface, without thickness, and is supposed to extend indefinitely. The best example we can get of a plane is a thin, perfectly flat sheet of paper. The size of the paper may be increased indefinitely in all directions, but as long as the paper remains perfectly flat any two lines drawn on it will be in the same plane. So when we say that a certain point A on the surface of a pulley lies in the center plane of another pulley, we mean that if an imaginary flat surface is passed through the center of the second pulley, perpendicular to the shaft, and the flat surface is extended far enough, it will pass through the point A on the first pulley. This will be seen by referring to Fig. 42, which is a plan and two elevations of a belt connecting two shafts at right angles to each other, one shaft being above the other. The pulleys are arranged to turn in the directions indicated by the arrows. In the left-hand elevation it will be seen that the center line of that part of the belt which is moving downward leaves the upper pulley at the point A. The line X Y is the edge view (or trace) of the plane which passes through the center of the lower pulley, and in order that the belt may stay on the lower pulley, the lower pulley must be so located on its shaft that this line X Y shall contain point A. It will be noticed that the part of the belt which is moving upwards is drawn off the lower pulley at a considerable angle side-

wise; but this is allowable, for a belt leaving a pulley may be drawn out of the center plane of the pulley. Now, referring to the right-hand elevation, we see that the upward-moving part of the belt leaves the lower pulley at B; S T is the trace of the center plane of the upper pulley, and this pulley must be so located on its shaft that S T shall contain the point B.

The detail for making the drawing for this kind of a belt will be considered a little later, under the subject of quarter-turn belts, the brief explanation at this point being given to make clear what is meant by the principle of delivering a belt into the plane of the receiving pulley.

Quarter-turn Belt. A belt arranged to drive two shafts which are at right angles with each other, as shown in Fig. 42, is called a quarter-turn belt. There are various other methods of arranging the belt be-

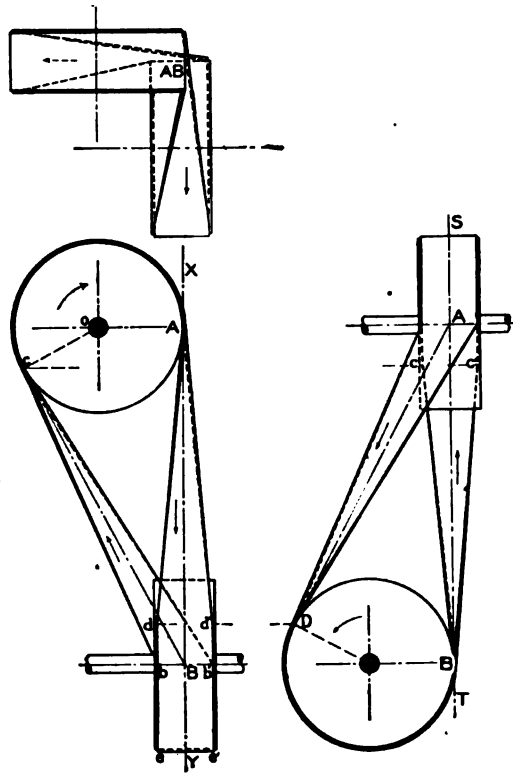


Fig. 42.

sides the one shown in Fig. 42, but as this is the simplest and easiest to understand we will study it first. With this arrangement the shafts must always turn in the same direction, for if the direction of rotation is reversed, neither pulley will deliver the belt into the center plane of the other pulley, and consequently the belt will not remain on the pulleys.

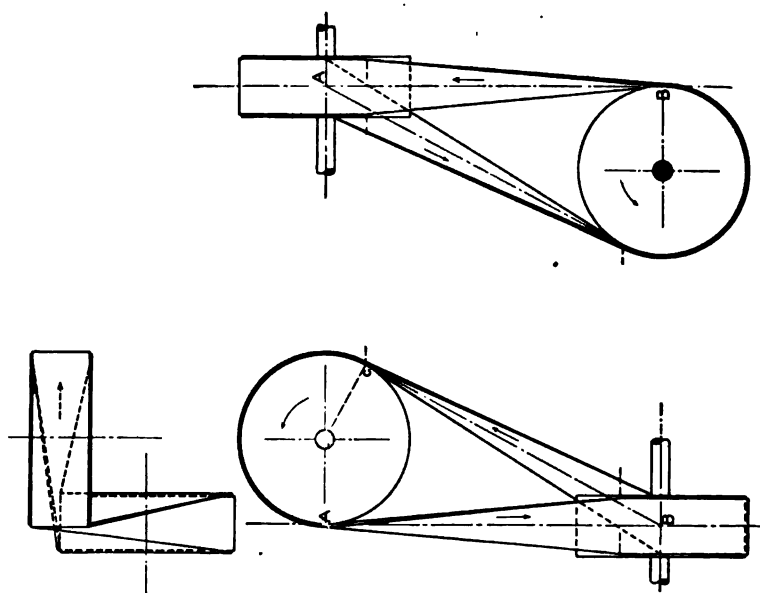
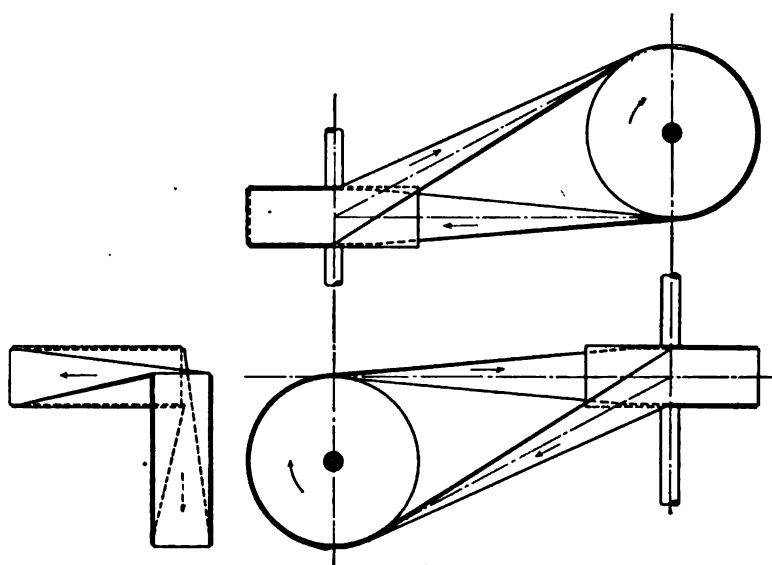
To draw the pulleys in their proper locations, having given

the location of the shafts with relation to each other, the direction in which each shaft is to turn, and the sizes of the two pulleys, proceed as follows: Draw first the two views of each shaft at the given distance apart, and put on the arrows to indicate the direction of rotation. Start with either pulley, let us say the upper one, and draw that view in which it appears as a circle, which in this case will be the left-hand view. Draw line *X Y* tangent to the circumference of this pulley at point *A* on the side which is turning downwards, *A* being on a horizontal line drawn through the center of the shaft. The point where *X Y* intersects the center line of the lower shaft will be the center of the other pulley, which will appear in this view as a rectangle of a length equal to the diameter of the pulley, and width equal to the width of the face of the pulley. Now draw the other view of the lower pulley, which will be a circle, and draw the line *S T* tangent to the circumference of this pulley at the point *B*, on the side which is turning upwards. The point of intersection of *S T* and the center line of the upper shaft will be the center of the rectangle which represents the side view of the upper pulley. The plan view may be placed above either one of the elevations, and is made according to the ordinary principles of projections, by studying out from the two elevations already made how the pulleys are located with relation to each other, and drawing them as they would appear if looked at from above.

A careful study of the figure will show that point *A* is vertically over point *B*, so that in plan the projections of the two points coincide, or, as it is stated in shop language, the leaving sides of the pulleys are in the same plumb line.

We now have the drawing completed as far as is necessary to determine the location of the pulleys, it being unnecessary to draw the arms, hubs, etc., of the pulleys in a drawing which is made to show location of pulleys on the shafts. It usually makes the drawing clearer, however, if the belt is shown also, and to make the drawing of the belt, the width and thickness must of course be known. The belt should always be put on so that the same side of the belt touches both pulleys when it is possible to do so. We will call the side of the belt which touches the pulleys the inside, and the other side the outside. Now referring

first to the left-hand elevation in Fig. 42, where the belt lies around the circumference of the upper pulley, from the point C, where the upward-moving part of the belt strikes the pulley, around to A, where the downward-moving part leaves the pulley, only the edge of the belt is visible, and is represented by drawing an arc of a circle from line O C around to O A with a radius equal to the radius of the pulley plus the thickness of the belt. The location of C may be found near enough for all practical purposes by drawing a line from B tangent to the upper pulley, C being the point of tangency, and O C is the radius drawn through C. In drawing the arc of the circle from O C to O A it is well to let it run by these lines a little way in the pencil drawing, and that part which is not used may be erased after the drawing is inked. The descending part of the belt leaves the pulley at A, and from that point to the place where it strikes the lower pulley it twists through an angle of 90° , coming out over the front of the lower pulley. The edge of the belt, which we see in its full thickness where it leaves the upper pulley at A, twists toward the left, less and less of it being seen as the belt descends, until at d , where it strikes the other pulley the two corners of this edge coincide, and from there to the bottom of the pulley we see this edge of the belt as a line. At the same time that the thickness of the belt has been disappearing from view, the outside of the belt has been coming into view, until at $d d'$ we see the full width of the belt, the outside corner being the one which is visible. The inside corner is behind the rest of the belt and is shown dotted in the figure, although it is usually omitted entirely. From d' to the bottom of the pulley the two right-hand corners coincide. Points d and d' are found by drawing the horizontal dotted line through D (right-hand view) and laying off on this line a distance equal to one-half the width of the belt each side of line X Y. From $e e'$ the belt goes up under and around the back side of the pulley to $b b'$, where it begins to be drawn off to the left, $b b'$ being on the center line drawn through the shaft, since, by glancing at the right-hand view, we can see that the upward-moving part of the belt leaves the lower pulley at B, which is on a level with the center of the shaft. After leaving $b b'$ the belt remains behind the pulley for a short distance, and is shown



dotted. It is projected at its full width at $b\ b'$, but as soon as it leaves the pulley it begins to twist toward the right, the left-hand edge gradually coming into view until it is seen at its full thickness where it strikes the pulley at C. At the same time, the *inside* face of the belt, which is toward the front when the belt leaves the pulley, gradually turns toward the right and appears narrower until it disappears from view, that is, is projected as a line. This completes the left-hand view, and the right-hand view is drawn according to the same principles, as is also the plan view.

An actual belt would not twist uniformly, and its corners would not appear as straight lines, but would curve, the form of the curve depending on the stiffness of the belt, the size of the pulleys, etc., but the straight lines are much easier to draw and represent the belt sufficiently well for all practical purposes.

Figs. 43 and 44 show what changes are made in the location of the pulleys and the appearance of the belt by changing the direction of rotation of the shafts. In Fig. 43 the lower shaft turns in the same direction as in Fig. 42, but the upper shaft turns in the opposite direction. In Fig. 44 the upper shaft turns in the same direction as in Fig. 42, and the lower shaft turns in the opposite direction.

Reversible Quarter to Turn with Two Guide Pulleys. The quarter-turn belt of the kind shown in Figs. 42–44 works satisfactorily, provided there is never any reversing of the direction of rotation. Sometimes, however, it happens that the shafting in a shop or mill is caused to make a few turns in the opposite direction from that in which it ordinarily runs. This might be done accidentally, or intentionally in the course of making repairs, and, as has already been stated, if it should occur, a quarter-turn belt such as described above would immediately leave the pulleys. With a small belt this might not be a serious matter, as it could readily be replaced, but with a large belt it would cause delay and might cause damage. Accordingly, if a large quarter-turn belt is to be used, it is desirable to have it arranged so that it can travel in either direction if occasion required. To accomplish this, one or more guide pulleys are used in addition to the pulleys on the main shafts, these guide pulleys being placed on auxiliary shafts so located as to con-

form to the general principle of belting, that the belt may always be delivered into the plane of the pulley which is to receive it. When guide pulleys are used, the main pulleys should be so located with relation to each other that the *receiving* side of the *driving* pulley shall be in line with the *delivering* side of the *driven* pulley, so that the part of the belt which transmits the power from the driving to the driven pulley (called the tight side of the belt) may go direct without passing over the guide pulleys, thus allowing the latter to guide the loose side of the belt back from the delivering side of the driving pulley to the receiving side of the driven pulley.

We will first study the arrangement when two guide pulleys are used. Let the shaft R, Fig. 45, be the driving shaft, and P be the driven shaft, and let the ordinary direction of rotation of each be as indicated by the arrows. Then A is the point on the driving pulley which receives the center of the belt from the delivering point B of the driven pulley, and if R and P are horizontal shafts, A and B should be in the same plumb line, thus giving the tight part of the belt a direct passage from driven to driver, making a quarter turn in its passage. To draw the pulleys so that this condition may exist, start with either shaft (say R) and draw that view which will show the pulley on it as a circle (in this case the left-hand view). Draw the line X Y tangent to the circumference at A, and the point where X Y intersects the center line of the shaft P will be the center of the driven pulley, which will appear as a rectangle in this view. Next draw the other view of the driven pulley, which will appear as a circle, and at the point B on the delivering side draw the line X' Y' tangent to the circumference of the pulley. The intersection of this line and the center line of the shaft R will be the center of the side view of the driving pulley (being the other projection of the point A). It will thus appear that both views of the line A B are perpendicular to a horizontal line, or, in other words, A B is a plumb line. This gives the required locations of the two main pulleys relative to each other.

Next draw the plan view of these two pulleys, these being constructed from the two elevations, according to the ordinary principles of projection.

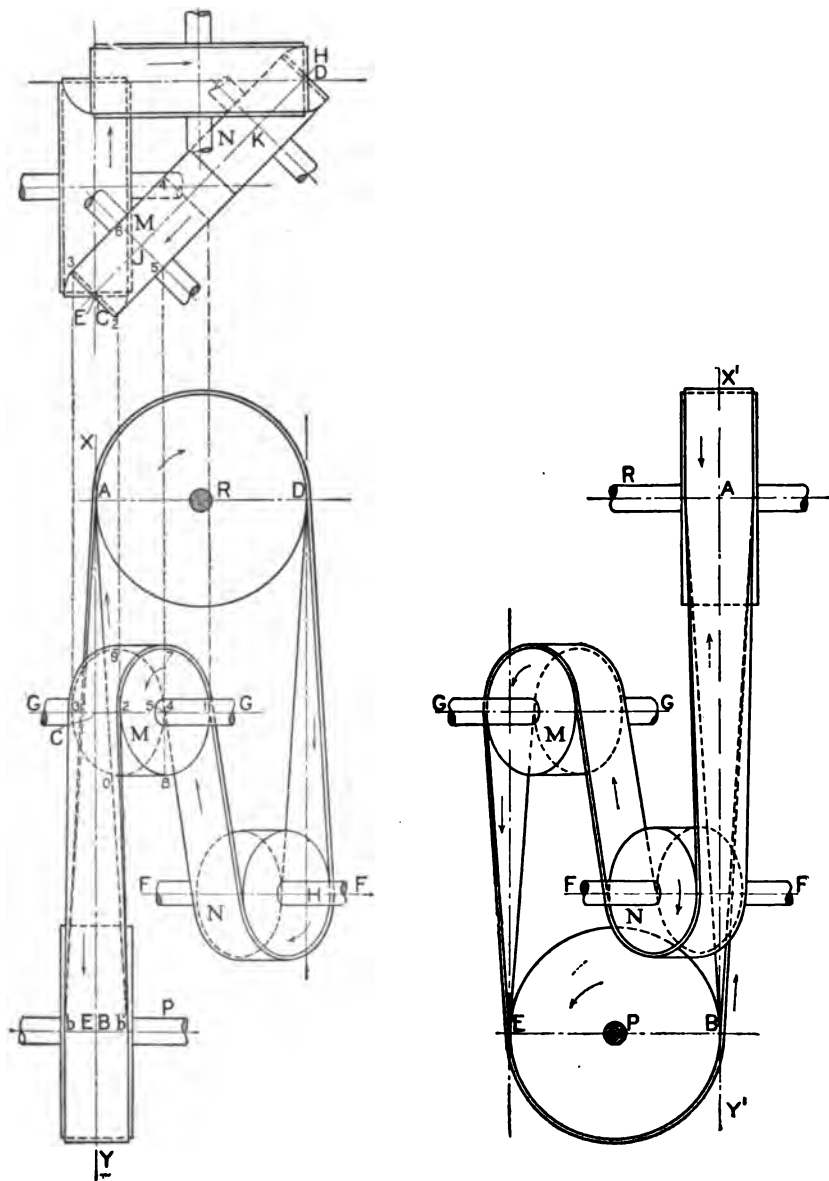


Fig. 45.

When two guide pulleys are to be used, the shafts on which both are located are horizontal if the main shafts are horizontal; the guide pulleys will therefore appear in plan as rectangles. We will accordingly draw the plan view of the guide pulleys first. They are to be so located that their center planes shall coincide, and that the point D, where the belt leaves the driving pulley, shall lie in the center plane of the guide pulley N, and that the point C, where the belt leaves the guide pulley M, shall lie in the center plane of the main driven pulley, in order that the belt will run in the direction indicated by the arrows. In order that the belt may run in the opposite direction if desired, the point E on the main driven pulley must lie in the center plane of the guide pulley M, and the point H of guide pulley N must lie in the center plane of the main driving pulley. In other words, points C and E must be in the same plumb line, and points D and H must be in the same plumb line. Then to draw the pulleys in plan, so that these conditions may exist, draw a line through E and D; this line will be the center plane of the two guide pulleys. From E, measure along the line EC a distance equal to one-half the diameter of the guide pulley M, and from the point J thus found draw a line perpendicular to the line ED; this line is the center line of the shaft on which M is located. In the same way, from D measure off along ED a distance equal to one-half the diameter of the guide pulley N, and draw a line perpendicular to ED through the point K thus found, giving the center line of the shaft on which N is located. Draw the rectangles as shown, representing the plan view of the guide pulleys.

To draw the elevations we must know the distance from the centers of the guide pulley shafts to the main shafts. This may be any convenient distance, it being desirable, however, to remove each guide pulley some distance from the main pulley which delivers to or receives from it, in order that the belt may not be obliged to turn in too short a distance. Draw the center line GG of the shaft for M, and FF of the shaft for N. The guide pulleys will appear in both elevations as ellipses. Consider first the pulley M in the left-hand elevation. Let fall the perpendicular (shown dotted) from point 5 in the plan, to center line GG, giving point 5 in the elevation. Along this perpendicular lay off

the distances 5-7 and 5-8 each equal to one-half the diameter of pulley M. The line 7-8 is the major axis of the ellipse which represents the right-hand edge of M. Now from points 1 and 2 in plan, drop perpendiculars cutting G G at 1 and 2 in elevation. Line 1-2 is the minor axis of the ellipse, and the ellipse 1-7-2-8 may be drawn by any geometric method for constructing an ellipse when its two axes are known. The ellipse 4-9-3-0 is drawn in the same way, and the lines 9-7 and 0-8 drawn tangent to the two ellipses complete this elevation of M. The elevation of N is found in exactly the same way. The same principles are used in getting the other elevation of the guide pulleys.

We have now completed the drawings of all the pulleys, and it only remains to draw the belt as it would appear in the different views. Here, as in the preceding cases, we will represent the edges of the belt by straight lines in the elevations, although they would really be curves. In the plan, where the belt turns as it drops directly from one pulley to another, the edges are represented by arcs of circles. Let us start with the left-hand elevation, with the tight part of the belt (that is, the part which goes directly from B to A). As we are looking at the pulleys in this view, B is on the back side of the pulley, and at B the belt is projected at its true width; as it rises it twists toward the right, so that the edge b' , which was at the right when leaving the lower pulley, recedes to the back edge of the upper pulley, while the edge b , which was at the left when leaving the lower pulley, comes forward to the front edge of the upper pulley; and we see this edge of the belt in its true thickness where it comes tangent to the upper pulley, and all the way around this pulley until it leaves it again at D. Here it begins to twist to the right again as it goes to the guide pulley N, goes around the lower side of N, then up over and down on the front of M, leaves M opposite the center, and drops direct to the front side of the main pulley, twisting again to the right, completing the quarter twist that was partly made when dropping from B to H. The appearance of the belt in the right-hand elevation is reasoned out in the same way, and a careful study of the figure should make it perfectly clear how to draw the belt. It will also appear that each side of the belt comes successively in contact with the pulleys, so that the belt is put

together with a twist in it. It is usually desirable to have only one side the working side, but if such were the case with this arrangement of pulleys it would bring a sharp twist in the belt at some part, which might be a greater objection than having the belt work on both sides.

Reversible Quarter Turn with One Guide Pulley.* Fig. 46 shows the arrangement of the pulleys for the belt to run in either direction, using only one guide pulley. The ordinary direction of rotation is that shown by the arrows. The upper pulley is the driver, and, as in the case where two guide pulleys are used, the tight part of the belt goes directly from one main pulley to the other, the slack part of the belt returning over the guide pulley. The shaft of the guide pulley must be set at an angle with both main shafts in order to guide the belt properly. The method of locating the main pulleys is exactly the same as in the case where the two guide pulleys are used, so that the explanation given for that case will apply here, and all we need to consider in this case is the location and drawing of the guide pulley. We will first consider the two elevations. The plumb line XY , as well as being the center line of the tight part of the belt, is the line of intersection of the center planes of the two main pulleys. Choose a point in the line XY , which may be anywhere along the line, depending on how far the guide pulley is to be from one or the other of the main shafts, but preferably about halfway between them. The point is marked M^h in the left-hand elevation, and M^v in the right-hand elevation. From M^h draw a line tangent to the upper pulley at D^h , and from M^v draw tangent to the lower pulley at E^v . The other projection of the line $M^h D^h$ will be $M^v D^v$, coinciding with XY in the right-hand elevation; and the other projection of $M^v E^v$ will be $M^h E^h$, coinciding with XY in the left-hand elevation. We now have two lines, MD and ME (shown respectively by their two projections, $M^v D^v - M^h D^h$ and $M^v E^v - M^h E^h$), which determine the plane of the guide pulleys and which are practically the center lines of that part of the belt which passes over the guide pulley, and our problem is one of projections. The problem is to find on the drawing paper the traces of the plane which contains the two lines, and which is the center plane of the

*This subject is optional.

guide pulley. Revolve this plane about one of its traces until it is parallel to the plane of the paper, so that the true angle between the lines will be shown; then draw the guide pulley tangent to the lines in their revolved position, and revolve the lines back to their former position, revolving the guide pulley back at the same time. To carry out this construction proceed as follows: draw a ground line anywhere between the two elevations, parallel to XY , and for the time being consider one of the elevations as a horizontal projection and the other as a vertical projection, remembering that our drawing is made as if projected on two planes located as in Fig. 55, Part IV, or, as it is commonly expressed, "in the third quadrant." We will treat the left-hand elevation as if it were the horizontal projection, and the right-hand elevation as if it were the vertical projection. Extend line $M^h D^h$ until it meets the ground line at d^h , and at d^h draw a perpendicular to the ground line meeting XY (which is the same as $M^v d^v$ extended) at d^v . Through d^v draw a line parallel to $M^v E^v$, and this line, which is marked VP , is the vertical trace of the plane which contains the lines MD and ME . In like manner find the horizontal trace by extending $M^v E^v$ to meet the ground line at e^v , erecting a perpendicular at e^v to meet $M^h E^h$ at e^h , and drawing HP through e^h parallel to $M^h D^h$. If the work is correctly done, HP , VP and the ground line will intersect in a common point. Now through M^h draw a line perpendicular to HP , meeting HP at p . Construct the right triangle $t m^h P$ (Fig. 47), making $m^h P$ equal to $M^h p$ on Fig. 46, and making $m^h t$ equal to the perpendicular distance of M^v from the ground line in Fig. 46 (that is, equal to $c M^v$). Then take the distance $p t$ (Fig. 47) and lay it off on the line $p M^h$ (Fig. 46) from p , thus obtaining point N . Join N and e^h , and through N draw $N g$ parallel to $M^h D^h$. The lines $N e^h$ and $N g$ are the projections on the horizontal plane of lines ME and MD respectively when the plane P , which contains these two lines, is revolved so that it is parallel to the horizontal plane. Therefore the angle $g N e^h$ is the true size of the angle between lines ME and MD . Now with a radius equal to the radius of the guide pulley which is to be used, draw a circle which shall be tangent to the lines $N e^h$ and $N g$. This circle is the center circle of

the guide pulley revolved parallel to the horizontal plane, and its center S is the revolved position of the center point of the guide pulley, and of course lies in the plane P . To revolve the center circle of the guide pulley back so as to get its two projections when it is in the position which it actually occupies with relation to the two main pulleys, we will first revolve back the point S to O^h . To do this, draw SK perpendicular to HP . Then in Fig. 47 lay off from P along the line Pt the distance PV , equal to SK in Fig. 46. Care must be taken to lay off this distance from P rather than from t , and in order to remember from which point to measure, the student can bear in mind that distances measured along the hypotenuse from P (Fig. 47) represent distances measured from HP (Fig. 46). Having thus found point V , draw a line perpendicular to $m^h P$, meeting it in o^h , take distance $o^h P$ in the dividers and lay it off from K along KS (Fig. 46), thus getting O^h . Then point O^h will be the center of the ellipse which represents the center circle of the guide pulley in its actual position. Point 2, where KS cuts $M^h D^h$, will be one end of the minor axis, and point 1, found by laying off $O^h 1$ equal to $O^h 2$, will be the other end of the minor axis. The major axis is found by drawing a line through O^h parallel to $M^h D^h$ and laying off along this line from O^h the distances $O^h 3$ and $O^h 4$ each equal to the radius of the guide pulley. Having now found the two axes of the center ellipse, it can be drawn by any geometric method for constructing an ellipse. We will next find O^v by prolonging the major axis of the ellipse just found until it meets the ground line at o^s , then erecting a perpendicular to the ground line at o^s to meet VP at o^s , through o^s , drawing a line parallel to the ground line, and from O^h drawing a line perpendicular to the ground line which shall meet the parallel through o^s at O^v . This point will be the vertical projection of the center of the middle circle of the guide pulley. The ellipse, which is the vertical projection of this middle

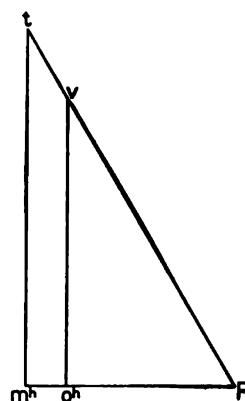


Fig. 47.

circle, is found from O^v in a way exactly similar to that in which the ellipse for the horizontal projection was found from O^h .

The next step is to draw the guide pulley and its shaft, and to do this we will revolve the center ellipse over in each view in such a way that we will have it projected as a line. We will take the horizontal projection first. Extend the major axis of the ellipse from O^h to o^4 , making $O^h o^4$ equal to the perpendicular distance of O^v from the ground line. Draw $O^4 1$ through point 1 parallel to $O^h o^4$. With o^4 as a center and with a radius equal to the radius of the guide pulley, cut $o^4 1$ at o^4 , and cut $D^h M^h$ extended at o^4 . Points o^4 , o^4 and o^4 will be in a straight line, and the line joining them will be the edge view of the center circle of the guide pulley. About this line $o^4 o^4$ draw a rectangle as shown, the width of the rectangle being made equal to the width of the face of the guide pulley. Through o^4 draw a line perpendicular to $o^4 o^4$, which will be the revolved position of the center line of the guide-pulley shaft. The method of revolving back to get the axes of the ellipses, which are the projections of the edges of the pulley in its actual position, and to get the projection of the shaft, will be clear from a careful study of the figure.

The vertical projection of the guide pulley is found by revolving over in exactly the same way, the distance $O^v o^7$ being equal to the perpendicular distance of O^h from the ground line. It is well to assume a definite length for the shaft, whether this be the actual length which the shaft would be made or not. The length assumed in the figure is $T^1 T^2$ (same as $T^3 T^4$), and half of this is laid off each side of o^4 in the revolved horizontal projection.

This completes the two elevations of the guide pulley. The plan is drawn as follows: find the projection $L L$ of the two ends of the shaft as shown by the construction lines, then revolve over by drawing line $K K^1$ at any convenient place parallel to $L L$, drawing perpendiculars through the two points L meeting the parallel line at K and K^1 , and laying off on these perpendiculars the distances $K^1 L^1$ and $K L^2$ equal respectively to $L^p P^p$ and $L^s P^s$ in the elevation. The line $L^1 L^2$, joining the points L^1 and L^2 thus found, is the revolved position of the shaft, and should be equal in length to $T^1 T^2$ and $T^3 T^4$ in the elevations.

We can now draw the rectangle which represents the revolved

position of the guide pulley at the middle of the line $L^1 L^2$, and find the ellipses from this rectangle in the same way as we found the ellipses from the rectangle in the other two views.

The belt is drawn in accordance with the same kind of reasoning as was used in determining the way the belt would look in the other kinds of quarter-turn belts which we have studied.

Belts connecting nonparallel shafts whose axes intersect.

It very often happens that a belt must connect two shafts which are on the same level, but which are not parallel. The connection can be made, whatever the angle between the shafts, by the use of two guide pulleys. If the two main shaft pulleys are of the same diameter, the belt may be made to run in either direction by putting both guide pulleys, or mule pulleys as they are often called, on the same shaft, which will be perpendicular to the plane which contains the axes of the main shafts. That is, if the main shafts are horizontal, the shaft for the guide pulleys will be vertical. If the

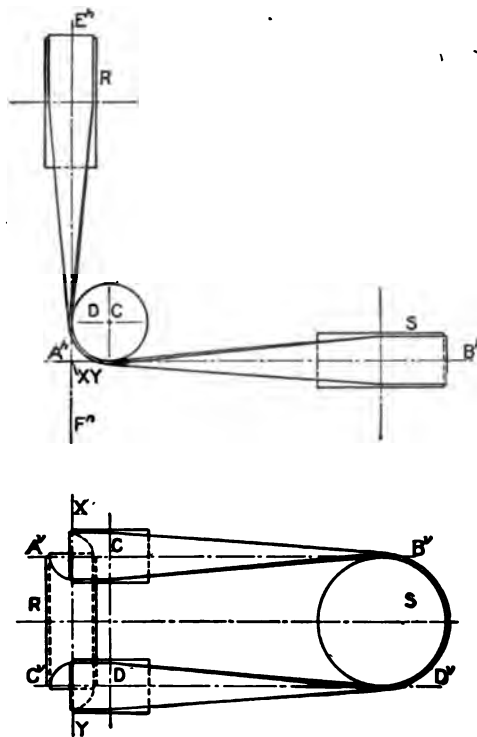


Fig. 48.

main pulleys are of different diameters, the guide pulleys may still be placed on the same vertical shaft, but in this case the belt can run in only one direction. If the belt is to run in either direction, the guide pulleys are placed on separate shafts, which are usually adjustable in position, so that they may be tipped at the proper angle to receive and deliver the belt.

We will first take the case where the two main pulleys are of the same size. Fig. 48 shows the arrangement, the upper view being the plan and the lower view the elevation. R and S are the two main pulleys, and C and D are the two guide pulleys. The line X Y is the line of intersection of the planes of the main pulleys.

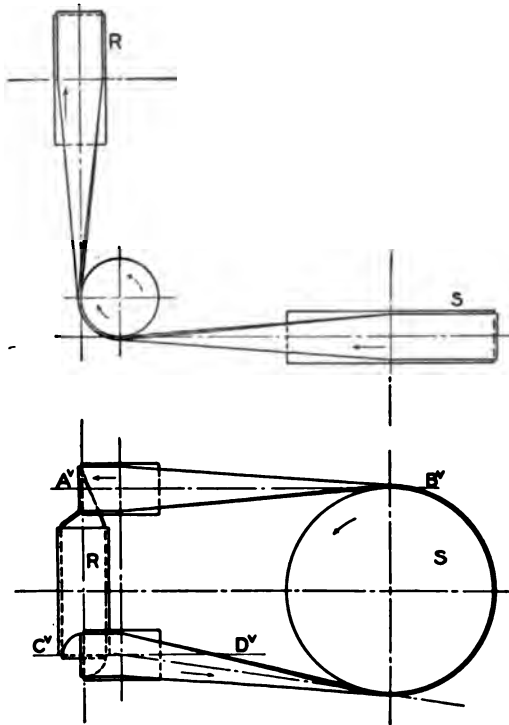


Fig. 49.

The location of the guide pulleys is sufficiently clear from the drawing without further explanation.

Fig. 49 shows the arrangement when the main pulleys are of different diameters. Here the pulleys can turn only in the direction shown by the arrows, for if the direction were reversed the belt would leave the pulleys. The pulleys in plan appear the same as in Fig. 48. In the elevation the upper guide pulley, which receives the

belt from S, has its center plane tangent to the pulley S at the point where the belt leaves S, as shown by the line A' D'. The lower guide pulley, which receives the belt from R, has its center plane tangent to R, as shown by C' D'. If the pulleys were to turn in the opposite direction, the upper guide pulley would have its plane tangent to R and the lower one have its plane tangent to S.

Belt Holes. Very often a belt has to pass through a floor or partition. The holes through which the belt runs should be large enough to be sure that the belt will never strike the sides, but it

is desirable that they should be no larger than is necessary to accomplish that result. Accordingly, the holes should be laid out so that they may be cut in the right place and at the proper angle, the first time. Figs. 50 to 52 show the method of getting the position of the belt holes for the various kinds of belts. The top of the floor only is shown, as it is all that would need to be used in drawing the belt holes, the holes being cut through the floor parallel to the center line of the belt.

In Fig. 50 we have a common open belt. The circles representing the pulleys are drawn, and the belt drawn around them. A short piece of the pitch line is also drawn in each part of the belt where it passes through the floor. These parts of the pitch line are simply lines parallel to, and half-way between, the lines which represent the outer and inner faces of the belt. Next draw the two rectangles which represent the plan view of the pulleys, and draw through them the center line R S. From the points E and H, where the pitch line intersects the line which represents the top of the floor,

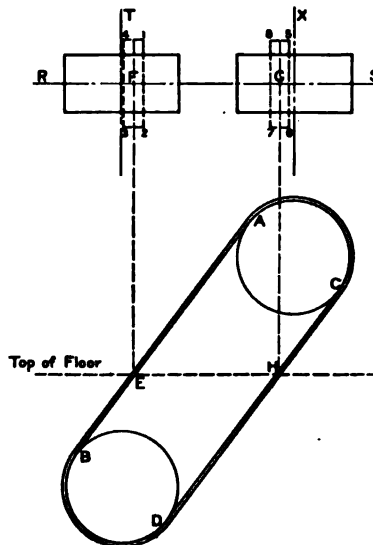


Fig. 50.

draw perpendiculars to R S meeting it in points F and G. F and G are the center points of the rectangles 1 2 3 4 and 5 6 7 8, which form the outline of the belt holes on the surface of the floor. The long dimension of the rectangles will be parallel to the shafts on which the pulleys are located. After the belt holes are so found, the distances of their center lines to the right or left of the lines T and X respectively (which are the center lines of the shafts), can be measured on the drawing, and the workman can mark them out on the floor by plumbing down (or up) from the shafts, getting the lines T and X on the floor directly under or over the center of the

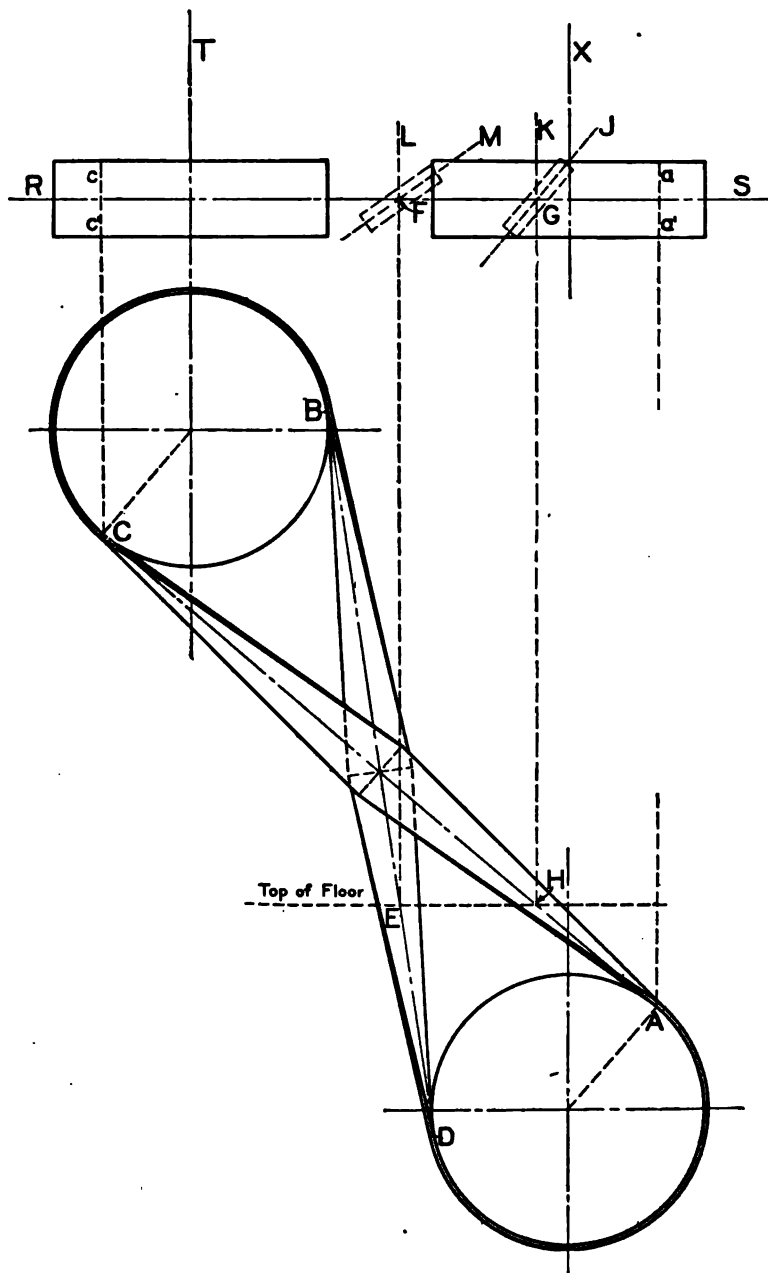


Fig. 51.

shafts, and thus locate on the floor the points F and G, and consequently the belt holes, from the dimensions taken from the drawing.

Fig. 51 shows how to draw the holes for a crossed belt. Draw the two views of the pulleys and the center lines A C and D B of the belt in the elevation; also the center line R S in the plan. It is well also to draw the belt complete in the elevation, as it makes it easier to determine which way the belt holes will slant. From points E and H, where the center lines of the belt intersect the floor line, draw E L and H K perpendicular to R S and meeting R S in F and G. The points F and G are the center points of the belt holes, and it only remains to determine the angles which the center lines of the holes make with T and X respectively. These will be the same as the angles made with H K and E L. When the belt is leaving the pulley at A, a line drawn perpendicularly across to its inner face would occupy the position indicated by the dotted line $a a'$ in plan, and the belt in passing from A to C twists through an angle of 180 degrees, and the line which was at $a a'$ will occupy the position $c c'$. Therefore, when the belt has passed from A to H it will have twisted through an angle which will bear the same relation to 180 degrees that the distance A H bears to the distance A C. That is, if $A H = \frac{1}{4}$ of A C, the angle J G K is $\frac{1}{4}$ of 180 degrees, or 45 degrees. Whether the angle J G K shall be laid off to the right or to the left of line H K, must be reasoned out by considering which way the belt twists in passing from A to C. The angle of the other belt hole (L F M) is determined in the same way.

Fig. 52 shows the method of finding the belt holes of a plain quarter-turn belt, similar to Fig. 50. The centers G and F in plan are found by projecting from the elevation, as shown by the construction lines. The angle which the center line of hole at G makes with the center line of the shaft is found by dividing 90 degrees in the ratio of the distances P and N. The angle of the center line of the belt hole at F with the center line of the shaft is found in a similar manner, by dividing 90 degrees in the ratio of the distance A E to E C. It is usually sufficiently accurate, however, after having found the angle at G, to draw the center line of the other hole parallel to it.

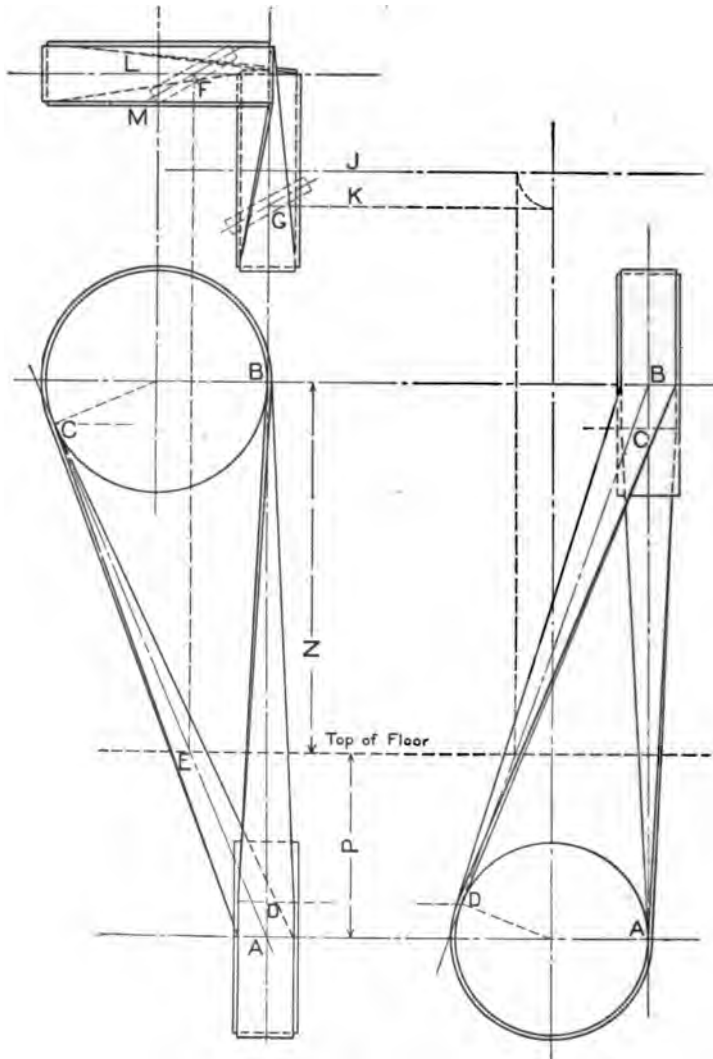


Fig. 52.

TOOTHED GEARING.

If we have a shaft B (Fig. 53), which has fastened to it a circular disc with a smooth circumference of radius B P, and parallel to and at a distance B A from the first shaft, another shaft A, which carries a disc of radius A P, it is evident that the two discs will touch each other at the point P, and if there were sufficient friction between the surfaces of the two discs, rotation of one shaft would cause rotation of the other. The number of turns that A would make would be to the number of turns that B would make as distance B P is to distance A P. In practice, however, the friction between the two discs would not be enough to transmit much power, so some more reliable means must be used.

Wheels having teeth on their circumferences, as shown in Fig. 54, are used in place of these discs. The two dot and dash circles drawn about the centers A and B and in contact at the point P, correspond to the discs of

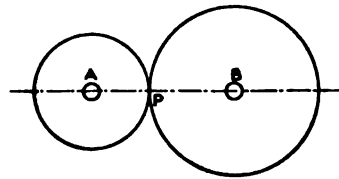


Fig. 53.

Fig. 53, and the gears may be said to be based on these circles, which are called the *pitch circles*. The diameters of these circles are called the *pitch diameters* of the gears. The point P, where the two pitch circles touch each other, is called the *pitch point*. Circles drawn through the outer ends of the teeth are called the *addendum circles*, and circles drawn at the bottom of the teeth are called the *root circles*. That part of the tooth outline between the pitch circle and the addendum circle, as P E, is called the *face* of the tooth, and the part between the pitch circle and the root circle, as P F, is called the *flank* of the tooth. The distance between the addendum circle and the pitch circle, measured on a radial line, is the *addendum*, and the distance between the root circle and the pitch circle, measured on a radial line, is the *root*. The root is made a little greater than the addendum, the difference between the two being the *clearance*. The distance from the center of one tooth to the center of the next, measured on the pitch circle, as G H, is the *circular or circumferential pitch*, and is equal to the circumference of the pitch circle divided by the number of teeth. In order to run together, two gears must

have the same circular pitch. The numbers of teeth in two gears of the same pitch are proportional to the circumferences and, consequently, the diameters of their pitch circles; and as the speeds of the two shafts which are connected by a pair of gears are inversely proportional to the diameters of the pitch circles of the gears, the speeds must also be inversely proportional to the number of teeth in the gears.

On rough gears the width of the tooth (as L M) is made a little less than the width of the space (K L), to allow for irregularities of construction. The difference in the width of the two is called the *backlash*.

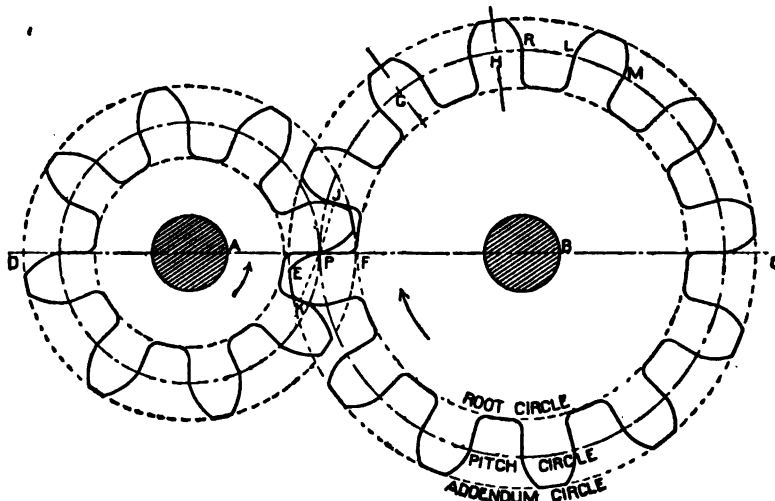


Fig. 54.

Although the circular pitch is a term which is used frequently in connection with gearing, there is another kind of pitch which is often used. This is the *diametral pitch*, and is equal to the diameter of the pitch circle divided by the number of teeth. The diametral pitch is not a distance which can be measured on the gear, as can the circular pitch, but is merely a term which is used to describe the size of the gear, and which bears the same relation to the circular pitch that the diameter of a circle bears to

its circumference. Since the circumference of a circle is 3.1416 times its diameter, the circular pitch can be found by multiplying the diametral pitch by 3.1416, or the diametral pitch can be found by dividing the circular pitch by 3.1416. In speaking of the pitch of a gear, instead of using the diametral pitch, which is often a fraction, it is customary to use only the denominator of the fraction. For instance, if the diametral pitch of a gear is $\frac{1}{2}$ inch, it would be spoken of as a 2-pitch gear.

If the gear A (Fig. 54) is driving the other gear in the direction indicated, there is a working point of contact between the teeth of the two gears at J and another at K; and as the gears turn and the teeth slide along each other, the point where a pair of teeth are in contact changes. Now, if from the point of contact, as J, a line is drawn to the pitch point P, the tooth curve should be of such form that this line is normal to the curve at the point of contact. That is, P J should be perpendicular to a line drawn tangent to the tooth curve at J. This condition should hold wherever the point of contact of the two teeth is, in order that the gears shall run smoothly and with a uniform velocity. A short way of stating this principle is: The normal to the tooth curves, at the point where they are in contact, must always pass through the pitch point.

There are two kinds of curves which are commonly used for the outlines of the gear teeth, and which fulfill the above condition. These curves are the cycloidal and the involute curves, the drawing of which was explained in Part II. Although ordinarily a draughtsman is not required to draw the exact outline of gear teeth, yet every draughtsman and every one who has to do with machinery, should understand the principles of gears; and the best way to become familiar with those principles is by studying the method of drawing the various kinds of gears.

Epicycloidal Spur Gears. Fig. 55 shows a pair of epicycloidal gears designed to run together. The centers of the gears are at B and A; the pitch circles are shown in dot and dash, and are in contact at the pitch point P. The circle whose center is C, shown dotted, by rolling on the inside of the pitch circle of the gear B, generates the hypocycloid P E, which forms the flanks of the teeth on gear B; and by rolling on the outside of the pitch

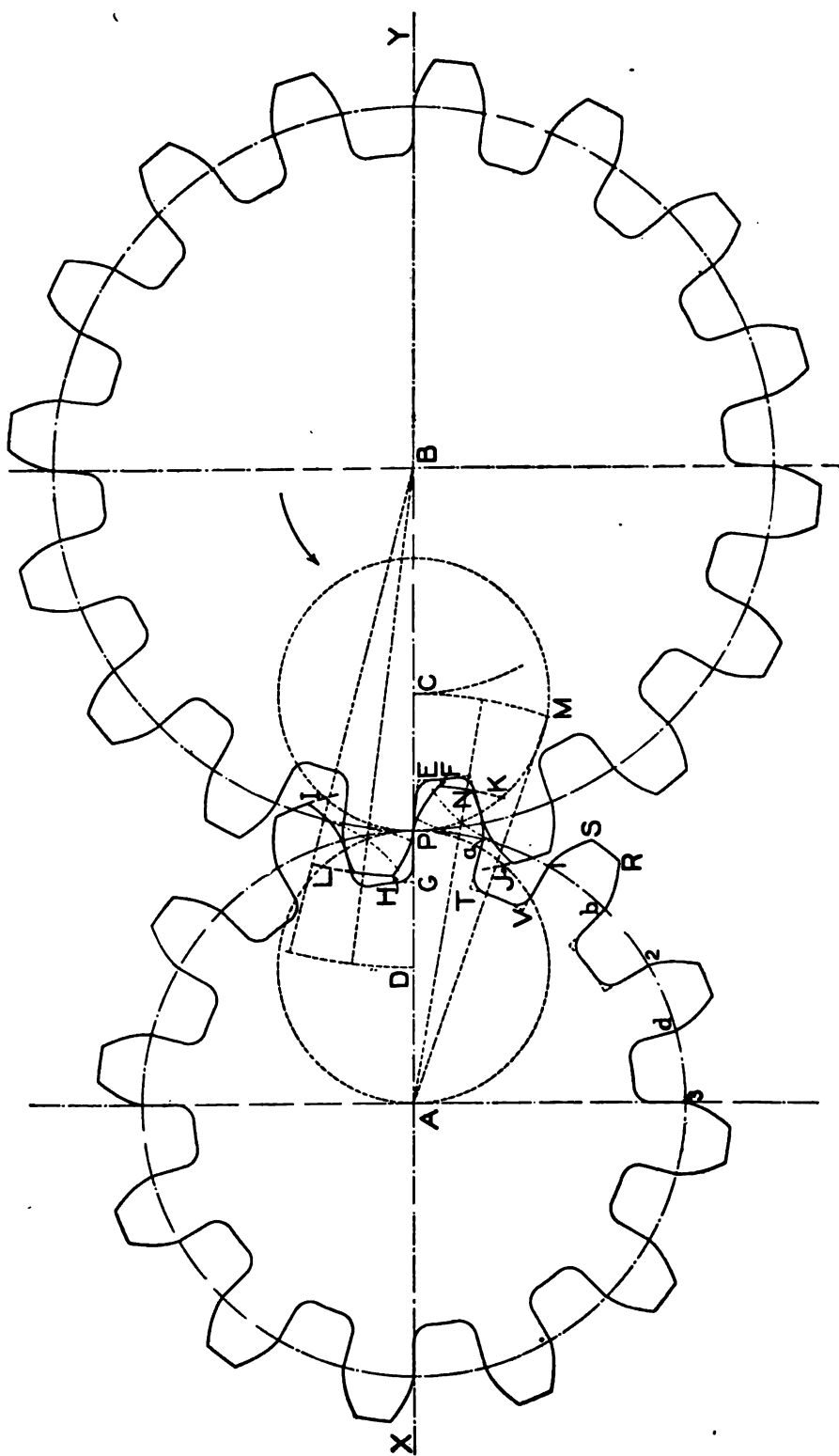


Fig. 55

circle of gear A, generates the epicycloid P F, which forms the faces of the teeth on gear A. In like manner the circle whose center is D, by rolling on the inside of the pitch circle of gear A, generates the hypocycloid P G, which forms the flanks of the teeth on A, and by rolling on the outside of the pitch circle of B, generates the epicycloid P H, which forms the faces of the teeth on B. The circles C and D are called the describing circles. If the gear B is the driver and is turning in the direction shown by the arrow, the flanks of its teeth act on the faces of the teeth on A from the point where they first come in contact until the point of contact reaches the pitch point; and from the pitch point on until the contact ceases, the faces of the teeth of B act on the flanks of the teeth of A. In other words, the hypocycloidal part of the tooth curve on one gear is generated by the same describing circle that generates the epicycloidal part of the tooth on the other gear, with which it is in contact. This must always hold true in order to have the gears run properly. The arc I P of the describing circle C, together with the arc J P of the describing circle D, forms what is called the path of contact; that is, the point of contact between the teeth is always somewhere on the line I P J. If the gear A were the driver, the direction of rotation remaining the same, the path of contact would be L P K.

To design a pair of epicycloidal spur gears we must have given the pitch (either diametral or circular), the diameters of the pitch circles, or the number of teeth, and something to determine the size of the describing circles. Manufacturers have found by experience what are the best ratios of describing circles to pitch circles, and gears are designed according to those ratios. It is not well to have the diameter of the describing circle greater than $\frac{5}{8}$ the diameter of the pitch circle, and it is better to have it smaller. If a set of gears is to be made, any one of which is likely to run with any other one, the same size describing circle must be used for the faces and flanks of all the gears; and this describing circle is often taken $\frac{5}{8}$ the diameter of the smallest gear of the set. Sometimes when two gears are not part of an interchangeable set, but are designed to run with each other only, the diameter for the describing circle for the flanks of each gear is

made equal to the radius of that gear, and when this is the case the flanks are radial straight lines, or, as it is usually stated, the gears have radial flanks.

In Fig. 55 the two describing circles are of the same size and equal to the radius of the smaller gear, thus giving radial flanks on this gear. Let us proceed with the design of this pair of gears, given dimensions as follows: gears to be 4 pitch (that is, as explained previously, four teeth per inch of pitch diameter); gear A to have 12 teeth; gear B, 16 teeth; addendum equal to the diametral pitch; clearance equal to $\frac{1}{4}$ of the addendum; describing circles each equal to radius of gear A. The steps in the process of drawing the gears are as follows:

First.— Calculate the diameters of the pitch circles.

Second.— Draw the center line X Y on the paper, and on this center line locate the centers A and B a distance apart equal to $\frac{1}{2}$ the sum of the two pitch diameters. Around these centers draw the pitch circles of diameters as calculated. This will make the pitch circles tangent at the pitch point P.

Third.— Calculate the radius of the addendum circles by calculating the addendum, and adding this amount to the radii of the pitch circles. Then draw the addendum circles with these radii.

Fourth.— Draw the root circles with radii equal to the radii of the pitch circles minus an amount equal to the addendum plus the clearance.

Fifth.— Draw the describing circles tangent to each other and to the pitch circles at the point P.

Sixth.— With the describing circle C rolling on the outside of the pitch circle of A, generate the epicycloid P F, continuing it until it meets the addendum circle of A. With the describing circle D rolling on the inside of the pitch circle of A, on the *opposite* side of line of centers from which the circle C rolled, generate the hypocycloid P G. Since the diameter of D is equal to the radius of the pitch circle of A, the hypocycloid P G will be a radial line; and consequently, after the student has become familiar with this fact, it will not be necessary to actually roll the circle to generate such a hypocycloid. The epicycloid P F and the hypocycloid P G together form one side of the tooth of gear A.

Seventh.—Divide the circumference of the pitch circle into as many equal parts as the gear has teeth, and through these points draw curves like the curve G P F. This may be done by making a templet of stiff paper that will just fit the curve G P F, and by means of this templet transferring the curve to the points 1, 2, 3, etc. Next find the points *a*, *b*, *d*, etc., halfway between 1 and 2, 2 and 3, etc., since there is to be no backlash, and through these points draw curves similar to G P F, but turned so as to curve the other way. Now by filling in with full lines that part of the addendum circle between the points F and N, R and S, etc., and filling in the root circle between T and V, etc., we have the outline of the teeth on the gear A. In practice, instead of making sharp corners at T and V, as shown by the dotted lines, fillets are put in with arcs of circles, these fillets being made as large as possible and still allow space so that the corner of the teeth on the other gear shall not strike.

Eighth.—Construct the teeth on the gear B in the same way as the teeth on A were constructed, the describing circle D generating the epicycloid P H by rolling on the outside of the pitch circle of B, and the describing circle C generating the hypocycloid P E by rolling on the inside of the pitch circle of B. The hypocycloid is not a straight line in this case, as the diameter of C is not equal to the radius of the pitch circle of B.

The following is the method of calculating the diameters of the pitch circles in the above construction. Since the gears are 4 pitch, their diametral pitch is $\frac{1}{4}$ inch, and the pitch diameter of each gear will be the number of teeth in that gear multiplied by the diametral pitch. Then gear A, having 12 teeth, will have for its pitch diameter $12 \times \frac{1}{4} = 3$ inches; and gear B, having 16 teeth, will have for its pitch diameter $16 \times \frac{1}{4} = 4$ inches.

If the pitch diameters had been given instead of the number of teeth, the latter would have been found by dividing the pitch diameters by the diametral pitch.

ANNULAR GEARS.

An annular gear is a ring with teeth on the inside of it. Fig. 56 shows such a gear, with center at A, meshing with a small spur gear, often called the pinion. The method of drawing such a

pair of gears is similar to that just described for two spur gears. Here the circle C by rolling on the *inside* of the pitch circle of A generates the *faces* of the teeth of A, and the circle D by rolling on the *outside* of the pitch circle of A generates the *flanks* of the teeth on A. The shape of the teeth of the pinion in the figure is found with the same describing circles placed at C' and D' to avoid mixing up the lines.

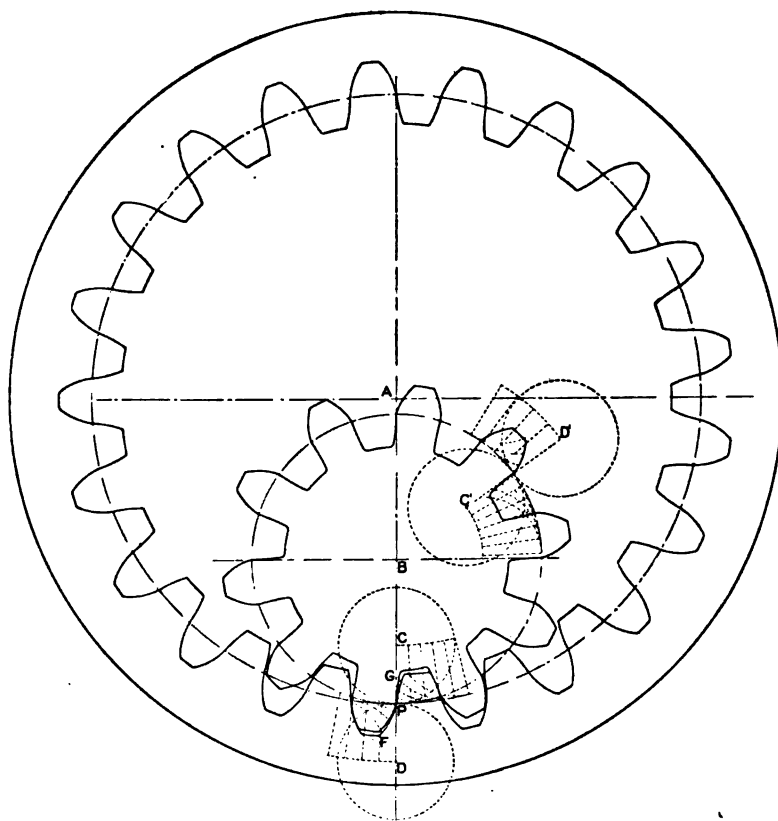


Fig. 56.

In designing an annular gear and pinion the diameter of the annular must never be so small that the distance from center A to center B shall be less than the sum of the radii of the two describing circles. If this should be the case, the teeth will interfere with each other.

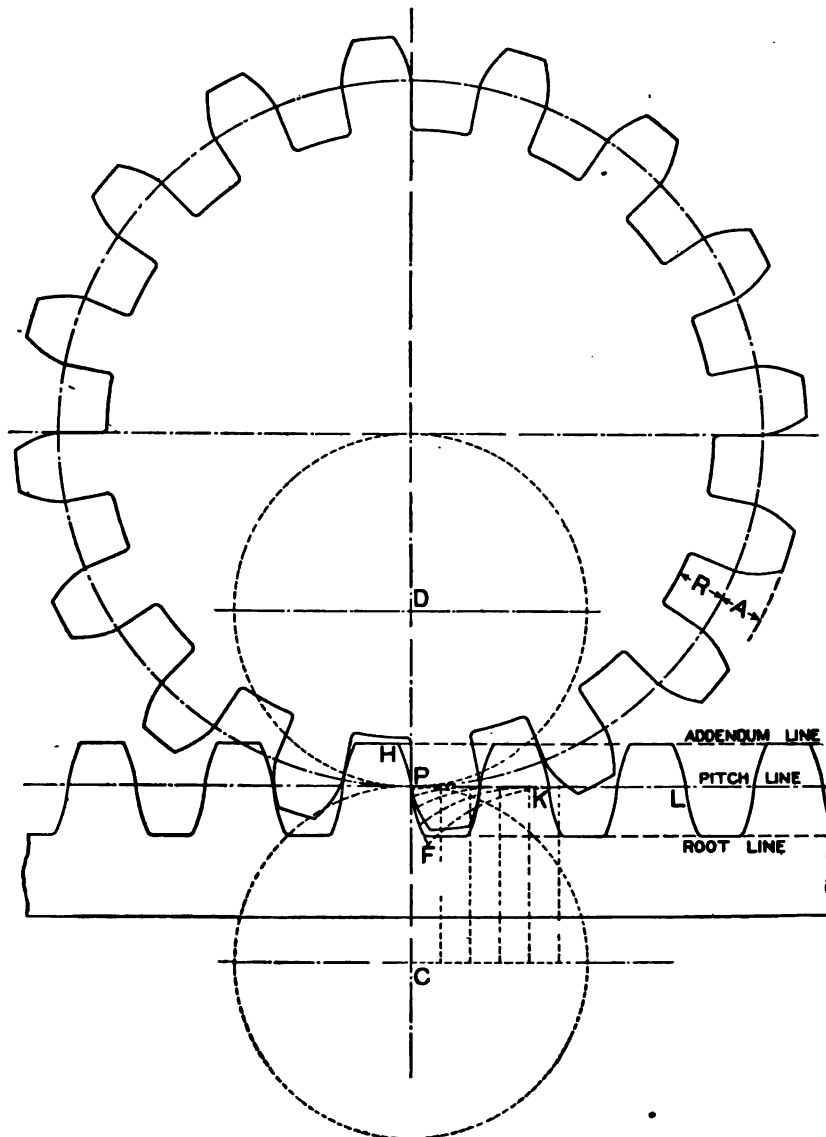


Fig. 57.

RACK AND PINION.

A rack is a gear whose pitch line is a straight line instead of a circle. Fig. 57 shows an epicycloidal rack in gear with a 16-tooth pinion. The describing circles are of the same size in the figure, although they might be of different sizes. The teeth on the pinion are drawn as described for Fig. 55, and the construction lines for drawing them are not shown. The curves which form the faces and flanks of the rack are cycloids. The describing circle C rolling on the pitch line of the rack, generates the cycloid P F, which forms the flanks of the rack teeth; and the describing circle D rolling on the pitch line of the rack, generates the cycloid P H, which forms the faces of the rack teeth. The addendum and root lines are drawn parallel to the pitch line, and at a distance from it equal respectively to the distances A and R of the pinion. The teeth are spaced off on the pitch line of the rack by laying off the distances P K, K L, etc., equal to the circular pitch of the pinion.

INVOLUTE GEARS.

Another form of gear teeth which is very common, is the involute. Fig. 58 shows parts of a pair of involute gears and the method of drawing the teeth. The circular pitch and the diameters of the pitch circles are found, and centers A and B located in the same way as described for epicycloidal gears. The pitch circles are in contact at the point P, as before. In involute gears the point of contact between the teeth is always somewhere on the line C D, the position of which is determined in designing the gears. This line passes through the pitch point, and the angle which it makes with the line X Y (the tangent to the pitch circles at P) is called the angle of obliquity, and is made what has been found by experience to give good results. It should not ordinarily be greater than 15 degrees. In designing the gears, having drawn the pitch circles, draw the line C D, making the desired angle with X Y, and with A and B as centers, draw circles tangent to this line. These circles are called the base circles. To find the addendum circles lay off on the line X Y the distances P M and P L, which, when possible, should each be as great as the circular pitch. From M and L draw lines perpendicular to C D,

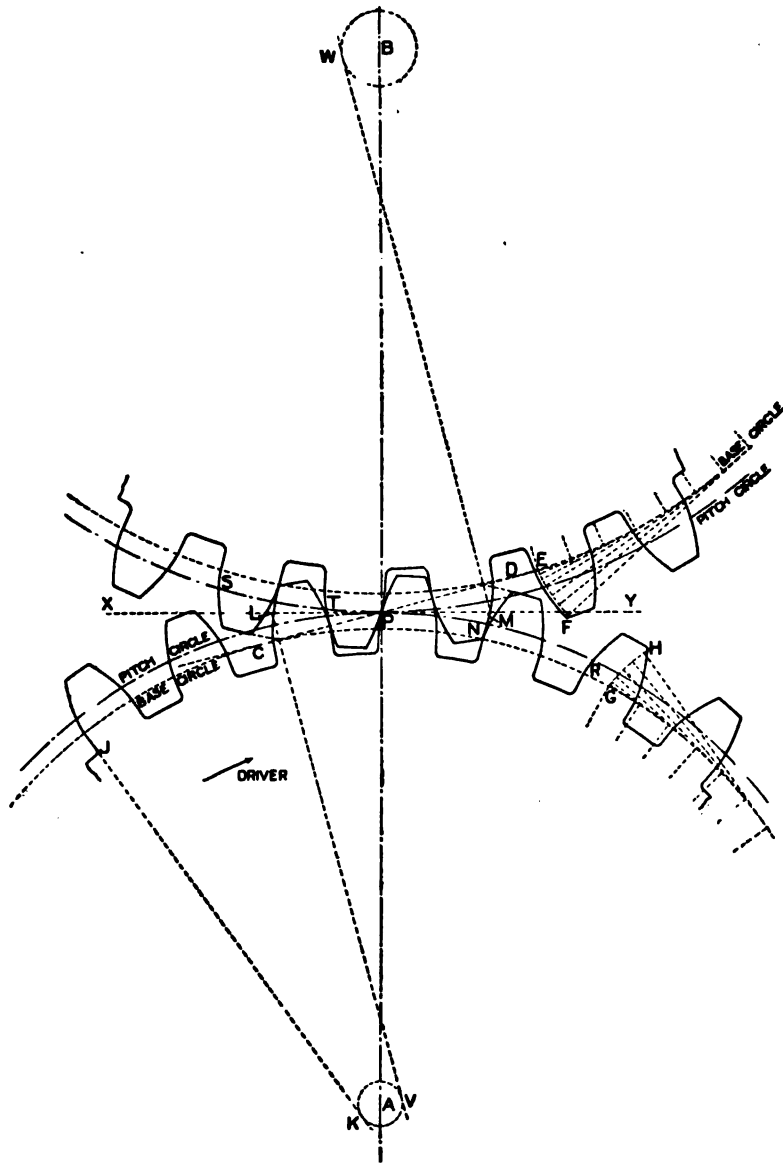


Fig. 58.

and draw the addendum circles through the points where these perpendiculars meet C D. The root circles are drawn by allowing a little clearance (about $\frac{1}{8}$ of the addendum). In laying off P M and P L care must be taken that neither one shall be so great that the point where the perpendicular strikes C D shall go outside of where C D is tangent to the base circle. P M plus P L must be at least equal to the circular pitch. At any convenient point on the base circles, as G and E, generate involutes in accordance with the methods described in Part II. Make templets to fit these curves, and by means of these templets draw in the tooth curves through P, N, R, S, T, etc., on the pitch circles, these points being found by spacing off the pitch just as described for epicycloidal gears. This gives us the working part of the teeth, and the remainder to the root circle is drawn by prolonging the perpendiculars, which were drawn through M and L, to V and W, and around the centers A and B respectively draw circles tangent to these lines. The flanks of the teeth are made straight lines tangent to the tooth curves already found and to these circles, as shown at J K. Small fillets are put in at the bottoms of the teeth.

BEVEL GEARS.

When two shafts whose axes intersect, are to be connected by gears, the gears commonly used are what are called bevel gears. The theoretically correct bevel gear is part of the sector of a sphere, but as the designing and making of such a gear is somewhat difficult, a cone is substituted for the sphere.

Fig. 59 shows a pair of *bevel gears* connecting two shafts whose axes intersect at right angles. The cones O P A and O P B are called the pitch cones, and the cones C P B and D P A the normal cones, and it is on these that the outlines of the teeth are laid out. The diameters B P and A P are the pitch diameters of the gears, and are found from the pitch and the number of teeth, just as the pitch diameters of spur gears are found.

To draw such a pair of gears we should have given the angle between the two shafts, the pitch and number of teeth in each gear (from which we find the pitch diameters), and the breadth of teeth P E. The gears might be either involute or epicycloidal. The addendum and root would be determined by empirical rules

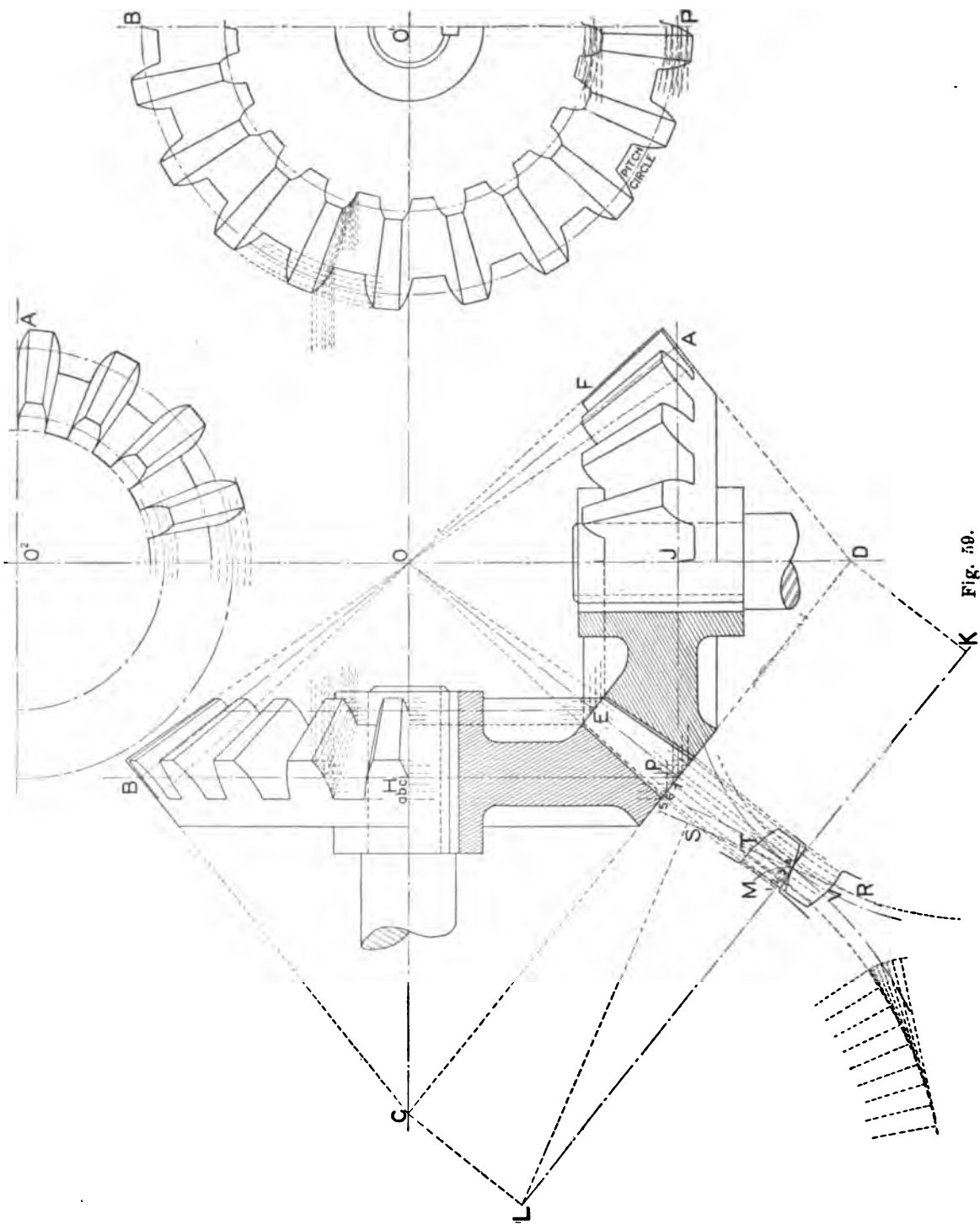


Fig. 50.

as on the other gears which have been discussed. The dimensions of the metal which forms the hub and the other parts of the gear, would be determined by the strength required, the place where the gear is to be used, etc.

The gears in Fig. 59 are 4 pitch, 16 and 20 teeth respectively. The addendum is as great as it can be. In this case it cannot be as great as the diametral pitch. The clearance is $\frac{1}{8}$ of the addendum. The gears are involute, with an angle of obliquity of 15 degrees. The shafts intersect at right angles. Start with point O and draw the center lines O C and O D, making an angle with each other equal to the given angle between the two shafts (in this case 90 degrees). Lay off on O C the distance O H equal to $\frac{1}{2}$ the pitch diameter of the smaller gear; through H draw a line perpendicular to O C. In like manner lay off on O D a distance O J equal to $\frac{1}{2}$ the pitch diameter of the large gear, and through J draw a line perpendicular to O D, meeting the perpendicular which was drawn through H at P. Make H B = H P, and J A = J P. From A, P and B draw lines to O, and we have the pitch cones. Through P draw C D perpendicular to O P, meeting O C and O D in C and D respectively. Join C B and D A and we have the normal cones. Through C, P and D draw perpendiculars. Lay off a distance C L = P M = D K. The lengths of C L, P M and D K may be anything convenient, provided they are all equal. With K and L as centers, and K M and L M as radii respectively, draw arcs of circles which will be tangent at M. These arcs will now be treated as pitch circles on which to design the tooth curves, being the development of portions of the normal cones. Through M draw the line of obliquity S R, and draw the base circles tangent to these lines. On the pitch circles lay off M V and M T each equal to $\frac{1}{2}$ the calculated circular pitch. If we should make the addendum equal to the diametral pitch, $\frac{1}{4}$ inch, the addendum circle of large gear would cut the line of obliquity beyond the point where R S is tangent to the base circle of the smaller gear, which we have previously learned should not occur, so we make the addendum circle of the large gear pass through R, and make the addendum of the small gear equal to the addendum of the large one. The root circles are drawn by allowing the clearance, as in the preceding gears.

One tooth on each gear is drawn as described for Fig. 58. With L as a center, draw a series of arcs (shown dotted), cutting the tooth which was drawn on the pitch circle which had L as a center, these same arcs cutting the line L K at points 2, 3, 4, etc.; from 2, 3, 4, etc., draw lines perpendicular to C D, cutting C D at 5, 6, 7, etc. From these points draw lines to O. Along P O lay off P E (which must be given), and through E draw a line perpendicular to P O, cutting 5 O, 6 O, etc. From the points of intersection draw other lines parallel to P B. With center O' taken at any convenient place on C O prolonged, and with radii equal in turn to a 5, b 6, etc., draw circles as shown. On the circle which is drawn with H P as a radius (marked pitch circle), space off the circular pitch, and on each of the circles in turn lay off the teeth of the same width as they are on the corresponding circles drawn through 1, 2, 3, 4, etc. The rest of the construction can be understood from a careful study of the figure. The other gear is drawn in the same way. Half of each gear is drawn in section in the figure to show the details of the casting.

PLATES.

Plates XX to XXIV inclusive, are to be drawn by the student to give him practice in applying the principles which he has learned of screws, springs, cams, belts and gears. These plates are to be made the same size as those of the preceding Instruction Papers of the course; that is, 11 inches by 15 inches, outside, with a margin of $\frac{1}{2}$ inch, making the part of the plate in which the drawing is done 10 inches by 14 inches.

PLATE XX.

The arrangement of this plate is shown by the reproduced plate.

Fig. 1 is to be a drawing of a right-hand single V-threaded screw 4 inches diameter, 6 inches long, pitch of screw 1 inch. The true helix is to be constructed as shown in Fig. 2 of the Instruction Paper. Show dotted construction lines for one turn of the helix.

Fig. 2 is to be the conventional representation of a single right-hand square-threaded screw 2 inches diameter, $3\frac{1}{2}$ inches long, pitch $\frac{1}{2}$ inch (2 threads per inch).

Fig. 3 is to be the conventional representation of a single left-hand V-threaded screw 2 inches diameter, $3\frac{1}{2}$ inches long, $4\frac{1}{2}$ threads per inch. Use the conventional form shown in Fig. 23.

Fig. 4 is to be a single right-hand V-threaded screw 1 inch diameter, $3\frac{1}{2}$ inches long, 8 threads per inch. Use conventional form shown in Fig. 23.

Fig. 5 same as Fig. 4, except that the thread is to be a double thread, 4 threads per inch ($\frac{1}{2}$ inch pitch).

Fig. 6 is to be a right-handed helical spring of $\frac{5}{16}$ inch round steel, inside diameter of helix $1\frac{3}{8}$ inches, length $3\frac{1}{2}$ inches, pitch $\frac{5}{8}$ inch, as shown conventionally in Fig. 8.

PLATE XXI.

Fig. 1 is to be a plate cam, which, by turning right handed, is to raise a slide (having a roller at its lower end) $1\frac{1}{2}$ inches with harmonic motion while the cam is making one-half of a revolution, then allow it to drop instantly to its original position, and remain at rest during the remaining one-half revolution. The center line of motion of the slide is to pass through the axis of the cam. The roller is to be 1 inch diameter, and at its lowest position its center is to be $1\frac{1}{2}$ inches above the center of the cam. The shaft of the cam is to be $1\frac{1}{2}$ inches in diameter and the hub 2 inches diameter. Show one view only. The details of the slide and roller of the hub of the cam are shown in the reproduced plate.

Fig. 2 is to be a plate cam, which, by turning left handed, is to raise a slide and roller, similar to that in Fig. 1, $1\frac{1}{2}$ inches with uniform motion during two-thirds of a revolution of the cam, and return it to its original position with gravity motion in the remaining one-third revolution. The center line of motion is 1 inch to the right of the axis of the cam, and at its lowest position the center of the roller is $1\frac{1}{2}$ inches away from the center of the cam. The dimensions for hub and for roller and slide are the same as for Fig 1.

PLATE XXII.

The reproduced plate shows plan and one elevation of two pulleys located on two shafts which are at right angles to each other. The student is to draw these two views and another elevation, showing the belt on the pulleys in all three views, and put

on arrows to show which way the pulleys will have to turn in order that the belt may stay on the pulleys. The dimensions are given in feet and inches, but of course the drawing cannot be made full size, but must be scaled down. The scale, as stated in the table, is to be 1 inch for every foot; that is, if the distance between the shafts is 8 feet, we draw it 8 inches, and everything else in the same proportion. In other words, everything is drawn one-twelfth of its actual size.

PLATE XXIII.

Draw an 8-tooth epicycloidal spur gear meshing with a 20-tooth annular. The gears are to be 1 pitch, addendum of each gear equal to 1 inch, clearance $\frac{1}{8}$ inch. Diameter of both describing circles 4 inches. Draw all of the teeth on the 8-tooth gear, and as much of the annular as there is room for on the plate.

PLATE XXIV.

Draw a 24-tooth involute gear meshing with a 32-tooth involute gear. Gears to be 2 pitch, angle of obliquity 15 degrees, addendum $\frac{1}{2}$ inch, clearance $\frac{1}{16}$ inch. Show as much of each gear as there is room for on the plate.

**SCREWS
AND
SPRINGS**
EXACT AND CONVENTIONAL
REPRESENTATIONS

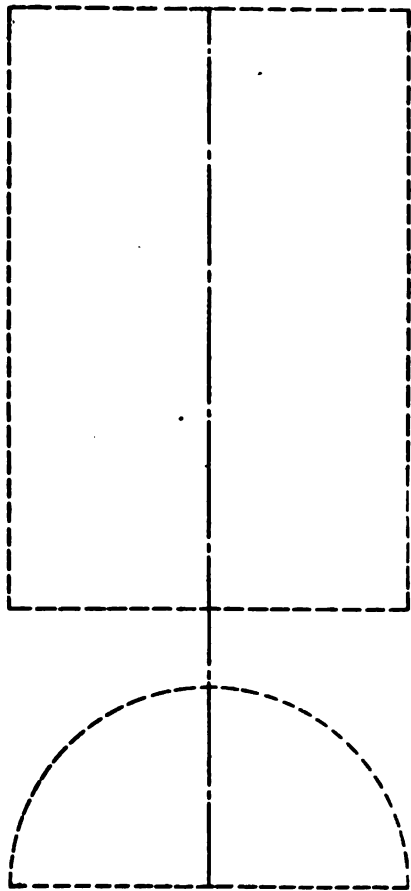


FIG. 1

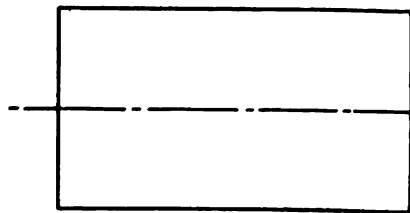


FIG. 2

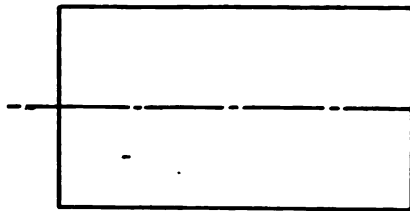


FIG. 3

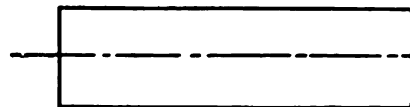


FIG. 4

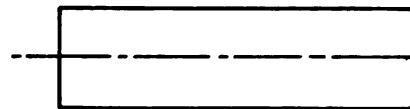


FIG. 5

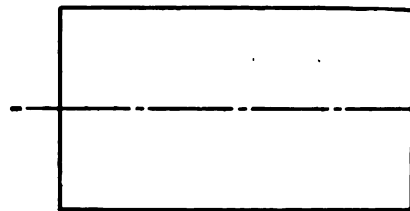


FIG. 6



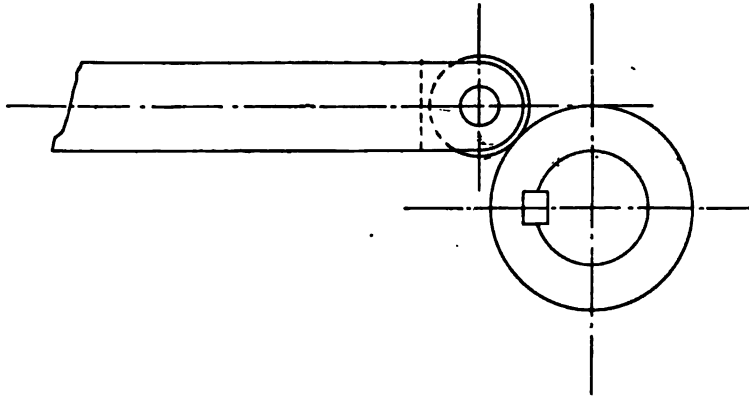


FIG. 2

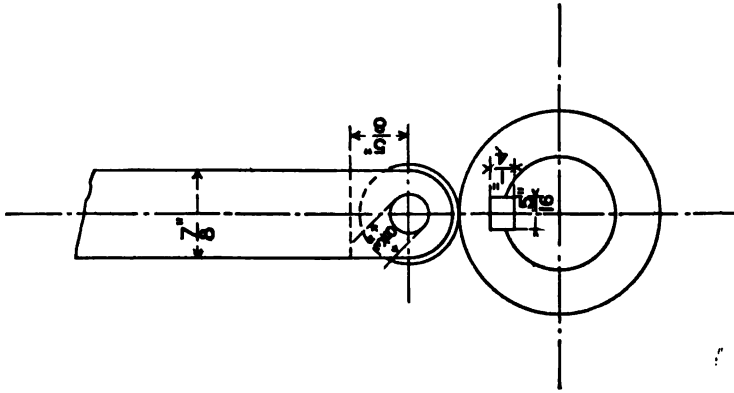
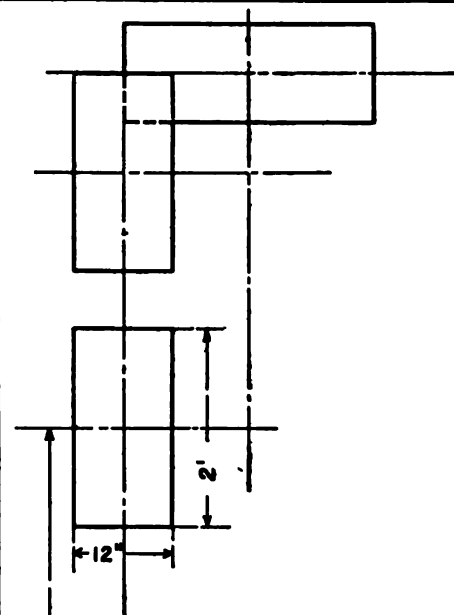


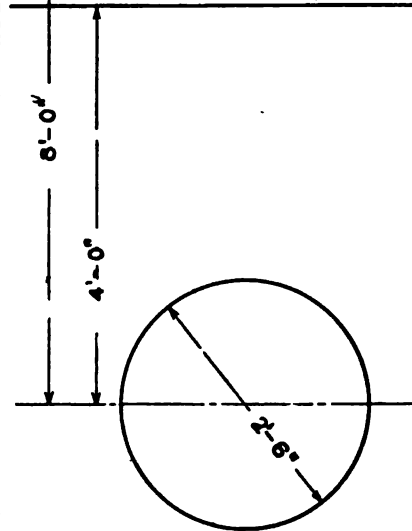
FIG. 1

QUARTER-TURN
BELT

SCALE 1" = 1'



Top of Floor



JUNE 20, 1901.

HERBERT CHANDLER CHICAGO, ILL.

SECTION 6.

MECHANICAL DRAWING.

PART VI.

WORKING SHOP DRAWINGS.

In Parts I to IV, inclusive, the fundamental principles of Mechanical Drawing were explained and illustrated. The production of working drawings has also been discussed to some extent, and the usual characters and symbols explained and applied. The elementary work already outlined has been treated chiefly from the standpoint of correctness of line representation considered by itself, without a detailed study of the use to which the drawings so produced are to be applied.

Evidently this is the proper method, for the student should gain a thorough understanding of the principles which underlie line representation before attempting to apply them to any extended practical use. In all of this preceding work it is intended that the theoretical principles shall overshadow any incidental references made to practical application, however true and pertinent the latter may be for purposes of illustration. Hence, before taking up any advanced work, the student should fully realize the importance, in fact, the absolute necessity, of thoroughly understanding the fundamental principles which have been outlined in the books which have preceded Part VI.

At this point the student must realize that a lack of proper elementary and fundamental training will make him "go lame" at every point of his course, and probably prevent the attainment of proficiency which otherwise would naturally and almost instinctively come with advanced study. It is the thorough and ready knowledge, always at his fingers' ends, of *all* the principles of Mechanical Drawing, which makes the expert draftsman.

Plan and Scope of Advanced Work. It is now intended to throw an entirely different light on the matter, and view the subject of Mechanical Drawing from a purely practical standpoint; viz., that of Utility. It is assumed that the student

understands and can use the principles which have been previously discussed.

If in a working shop drawing we choose to modify any of these theoretical principles, it will be because of increased value in *Utility* of the drawing. For example, we may desire to omit some portions of an elevation or plan or side view of a complicated casting, because certain details will thus be more clearly brought out. We may make a "zigzag" section to show construction which, by absolute fidelity to theoretical principle, would be confused, or hidden in a maze of dotted lines. We may find it convenient to place in some unoccupied corner of a drawing a layout which could not be in the least justified by any rule of projection. A multitude of transgressions like these occur on good drawings, and they are certainly justifiable from the standpoint of *Utility*, which is the true ultimate end sought for in a practical shop drawing.

These variations from the theoretical are not strictly conventionalities, because they are not classified or established, so far as we know, but are the spontaneous outgrowth, as the occasion demands, of the draftsman's purpose to make his drawing one of greatest *Utility*. He can, however, safely transgress a principle only when he thoroughly knows the principle; otherwise a blind deviation from the theoretical path will inevitably lead to difficulty.

All of the above is intended to impress the student with the idea that theoretical principles are his best, in fact, his only tools to work with; but they are not "self-hardening," like "mushet" steel; they are like the finest grade of tool steel, which must be tempered and ground and used with the best judgment of the operator, to secure the most satisfactory results.

Student Drawings. A student's early drawings are usually unsatisfactory, even to himself. Somehow they do not look like those seen in shops, and as a rule he is unable to see why this is so. Of course the difference is to some extent due to the experience of the professional draftsman. However, the superior results of the latter's work are attained largely through his systematic and workmanlike habits of execution. It should encourage the student in his early attempts to know that these essentials to

the infusion of life and shop spirit into a drawing can be analyzed, outlined and grasped at the outset by earnest, intelligent effort, and really good workmanlike results obtained. To discuss, and if possible to impart these essentials of a working shop drawing to the student, is the purpose of the present book.

Essentials. The two chief essentials of a shop drawing, under which general heads a multitude of detail requirements can be summed up, are:

(1.) Absolutely complete and definite instructions from designer to workman.

(2.) Least possible cost in dollars and cents of production of the drawing measured by the draftsman's time.

It makes no difference how much we may attempt to disguise these two elements, the fact will still be apparent that "*complete instructions furnished for the least money*" is what the manufacturing shop is after, and what will be assumed as a basis for judgment as to highest commercial utility.

Completeness of Drawings. As to the first point, that of completeness and definiteness of instruction, there must be no question of degree. If the information which the drawing furnishes is positive and complete, the drawing is good. If doubt arises in the workman's mind as to what the designer intended by a certain line or dimension, or if the dimension be omitted, the drawing is bad. There is no middle ground. The instructions are either present or absent, and the drawing good or bad accordingly.

The workman of to-day is not permitted to assume dimensions or shape. It is his business to execute the draftsman's orders; it is, however, often his privilege to choose his own way of doing it, but further than this modern practice does not allow him to go. He is held as rigidly to the orders specified by the drawing as the locomotive engineer is held to his bit of tissue telegraphic order to proceed, without which he dare not enter the next block. The drawing is supreme; it is official; it must be plain, direct and all-sufficient. It is the draftsman's business to make it thus, and he is not a draftsman until he does.

This idea of positiveness must be thoroughly absorbed by the student. Positive action must be a habit which controls his every

move, which marks every dimension he prints, which directs every line he draws. Every line must mean something, must have a definite reason for existence, must be necessary to illustrate the idea which he wishes to convey to the workman, and every line must be a definite measurable distance from every other line, so that its location is fixed beyond a doubt. Lines which mean nothing, and cannot be measured, have no place on the drawing; they only confuse it.

A good picture of a machine could scarcely be called to the same service as a good drawing of it. The picture might give us an excellent idea of the machine, but for the purpose of the actual construction the picture is useless, while the drawing is of positive value. This value exists simply because of, and in proportion to, the completeness of detail which it shows. Hence in making a shop drawing the picture idea is entirely subordinate to the idea of *Utility*, the latter in fact being the measure of its value.

There are certain classes of drawings—of which the Patent Office drawing is a good example—in the making of which the picture idea is predominant. Here the purpose is to illustrate mechanisms, not construct them; hence the function of the drawing is in no wise that of the working shop drawing, and as such does not fall within our discussion.

Cost of Producing Drawings. The second general element involved in producing shop drawings is their cost, as measured by the draftsman's time. It is somewhat subordinate to the first element, for the drawing must be a good one, judged by an absolute standard, whatever the time or cost necessary to produce it. Cost, however, is an important item, and cannot well be overlooked. It is inevitable that in any enterprise economy will ultimately be sought, whatever extravagance an imperative original demand may have permitted. This is as true in the production of drawings as in the case of manufactured articles of trade. Drafting-room labor is a relatively high-priced service, and the salary list easily assumes considerable proportions, so that wasteful excesses count up rapidly. One of the qualifications of proficiency invariably required for this department of shop organization is rapidity of execution. This is not as dependent upon personal traits as at first might be supposed. A man may so husband his time and

direct his efforts that he will easily distance his neighbor of more rapid motion. The latter may have less ability to make his energies count, and lack of judgment as to when just enough, and no more than enough, energy has been expended on his drawings. From the standpoint of *Utility*, the function of a drawing is fulfilled when it has reached the stage that it *completely* instructs; more time spent in elaboration is wasted, and is an unnecessary and therefore extravagant expenditure. The student must fully realize this. In his earnestness to produce finished and complete work he must constantly strive to accomplish results in the least possible time. This does not mean careless haste; far from it. A complete shop drawing cannot be made by short cuts, but through a systematic building of line on line, dimension on dimension. This is in sharp contrast to a haphazard habit of developing a drawing, first a line here and then a figure there, with no definite purpose in mind, and no hint as to when the drawing is actually completed.

The one method constitutes the efficient draftsman who works easily, receives a high salary, and is worth it, because he wastes no time in unnecessary labor. The other marks his unfortunate brother, plodding laboriously far behind, receiving a small pittance per hour, and worth less, because he does uncalled-for labor, and loses his definiteness of purpose in a maze of unexplainable lines and figures.

A working shop drawing, commercially considered, may well be defined as being "Complete instruction from designer to workman issued at minimum expense."

This definition should be memorized by the student, and constantly kept in mind while making a drawing. The preceding pages should be re-read with this in view until the full spirit is appreciated.

The maxim as given above, if faithfully adhered to without modification, answers nearly every question that can be raised as to the excellence of a drawing. It can be used as a standard of judgment, whatever system of lines or symbols may be in vogue. It permits a draftsman to adjust himself to the rules of any shop or drawing-room, and yet produce a good drawing and satisfy his employer.

A drawing which is cheaply produced and at the same time does perfectly that for which it was made, that is, convey complete instruction, is beyond commercial criticism.

Method of Procedure. As the general objects to be attained in a working shop drawing have now been presented, it is necessary to indicate in detail how the work may be properly accomplished. In order to do this, it is proposed to produce systematically a full set of working drawings of a familiar and comparatively simple machine. The methods used will be those of a designing detail draftsman, producing commercial work fit for shop use. In the progress of the work, from its beginning in the rough, though accurate, pencil layout, to the completion of the tracings and the order sheets, the same bold style, clearness, directness and businesslike spirit which the shop atmosphere and surroundings would naturally supply, will be emphasized, and so far as possible imparted to the student. It is expected that the student will follow the text closely and study the plates carefully, endeavoring to familiarize himself with every detail illustrated. The more closely he is able to apply himself in this respect the more will he be able to partake of the life and spirit which is intended to be conveyed, and without which the true character of the work can be but poorly developed.

Incidentally, several purposes will be fulfilled by this treatment.

Ability to read drawings quickly and intelligently is almost as important as making them, and it is expected that the study of the plates, with a view to thoroughly understanding every line, will develop proficiency in the art of reading drawings.

The discussion in the text, of not only the form of the machine parts themselves, but also the tools and shop processes to produce them, affords considerable insight into the influences affecting good machine design. Without introducing any mathematical analysis or investigation, which is beyond the province of this book, much practical consideration as to the restrictions imposed by existing shop methods upon theoretical construction will be suggested, and the student encouraged to use his judgment thereon.

In the preliminary layouts the actual "sketchy" appearance

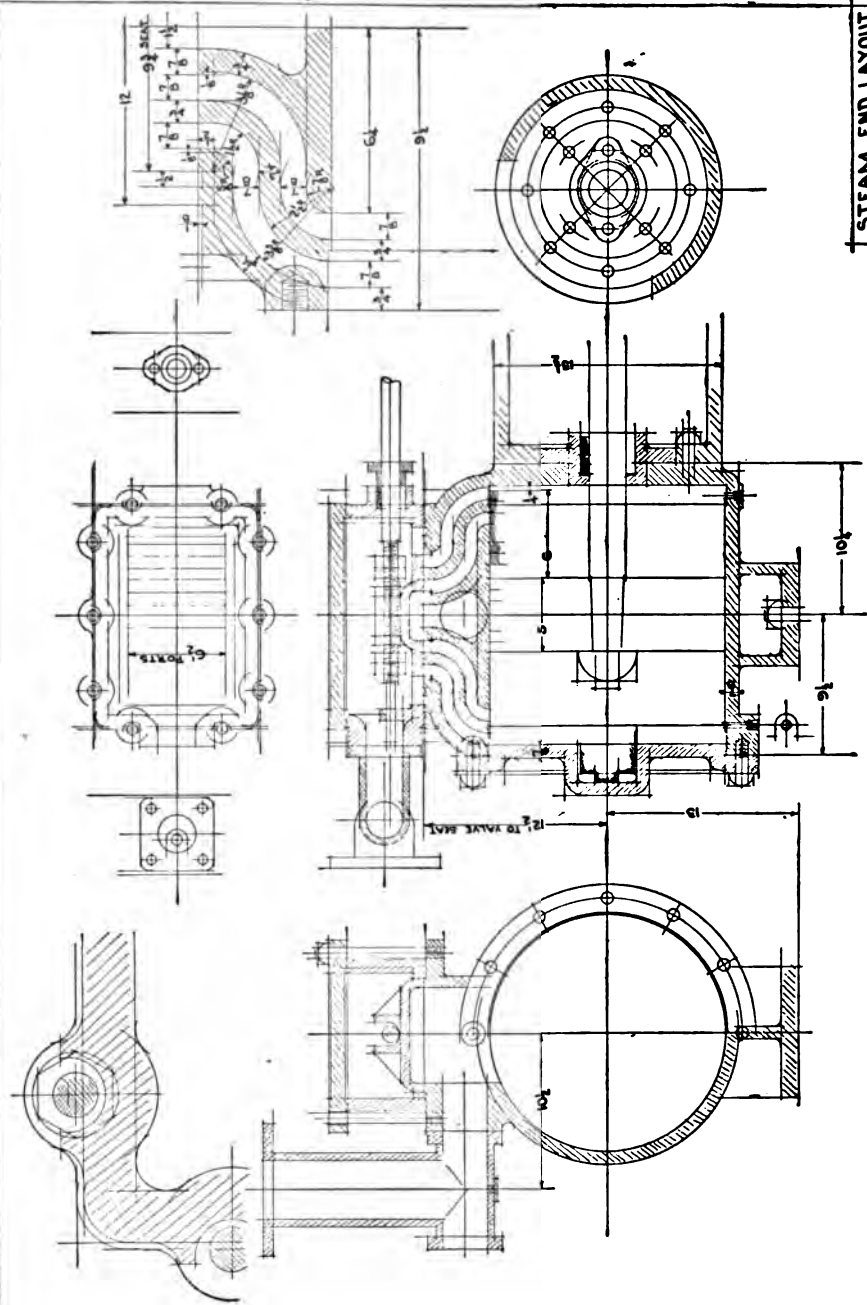
of the pencil drawing will be imitated as far as possible, so that the student himself may imitate and catch the bold dash, yet fine accuracy, of the line-work, which is characteristic of the expert draftsman.

The completeness of a *set* of drawings is as important a lesson as the completeness of each drawing itself. In this is involved the proper arrangement and classification of details, the foundation layout, and the system of order sheets for getting work into and through the shops. This is a feature which very strongly affects some of the finishing touches to a drawing, for it is so easy to omit a "few last things" and turn in an uncompleted sheet. Every draftsman knows how many little things come up toward the close of a job involving complete drawings of a machine, and how strong the tendency is to omit them, and relieve himself of somewhat tedious details. The result is irritation and delay when the drawings get into the shop, and they return to the drawing room to be fixed up at a time probably inconvenient for all parties concerned. A good draftsman will turn in a *complete* set of *complete* drawings. It is highly important that the student grasp this idea, and study his work accordingly.

DUPLEX PUMP PLATES.

The typical set of plates chosen for this book in fulfillment of the above purposes, takes up the study of a simple, duplex steam pump. This particular type of machine represents the simplest and most elementary form of the steam engine in modern use in respect to valve gear and controlling devices. It is not an economical machine, yet its principles lie at the foundation of the economical high-speed engine, the latter being produced through a modification of the uneconomical valve gear such as is found on a pump of the type chosen, rather than through any radical change of construction as to the body of the machine. Hence the study of a steam pump may well precede that of higher forms of the steam engine. It is hoped that the study will so interest the student that he will be led to further investigation and development not only of the steam engine itself, but of that highly important division of modern engineering,—pumping machinery.

Thus we note another point of advantage in the study as out-



lined. The power end of the machine introduces us to the steam engine; the load end is the beginning of the engineering of pumping machinery.

Rating of Pump. A steam pump is rated by the bore of its cylinders and length of stroke, all being given in inches. A "16 $\times$ 8 $\frac{1}{2}$ $\times$ 12 pump" means that the steam cylinder is 16 inches in diameter, the water plunger 8 $\frac{1}{2}$ inches in diameter, and the nominal length of stroke 12 inches. These sizes are always given in the same order, beginning with the diameter of the smallest cylinder (in case there is more than one), then the diameter of water plunger, the common stroke of both being placed last. This expresses to the mechanic the rating of the pump in the clearest style and briefest language.

The pump illustrated here is designed for standard service, operating under a steam pressure not to exceed 100 pounds per square inch, water pressure not to exceed 150 pounds per square inch, and the rated capacity based on an average piston speed of 100 feet per minute being about 550 gallons. This requires that each side of the pump shall handle 275 gallons, and being double acting, shall make 100 reversals or 50 double strokes per minute.

Plate A. Steam End Layout. This plate illustrates, as nearly as reproduction can accomplish, the pencil layout of the steam end. It is the first work of the designing draftsman. The drawing as shown is exactly the type of layout which he would turn over to a detail draftsman, whose duty it would be to work up detail shop drawings therefrom.

The character of this drawing should be carefully studied. Remember that it is a layout, nothing more; also bear in mind that it is an exact, measurable working sketch. Attention is called to the sharpness of the lines, especially to the clean-cut intersections. Note the boldness, dash and businesslike style, the free-hand cross-section lines roughly put in. There is no hesitation or worry as to where the end of a line shall be, or whether it crosses other lines which it theoretically should not. The intersections are allowed to indicate the termination of lines, and the rough section lines pick out the parts and separate them clearly to the eye. There is the spirit in this layout of confident, definite and rapid action, with no thought for absolute finish in line-work, but

with every thought for absolute results as to measurable dimensions.

The data for the production of Plate A by the student are rather more complete than he would usually find in practice. Plates E, F and G show many details fully.

The steam cylinder and head, however, as shown in Plate G, are not dimensioned, and the student's problem is to produce this plate complete, with finish marks, dimensions and necessary data for a working drawing. In order to do this it is first necessary to work up Plate A with exactness, in pencil, and see that all parts go together properly. Then the detail of cylinder and head may be made separately by measurement of the layout drawing, and Plate G produced.

For this work the ordinary brown detail paper is very satisfactory. A hard lead pencil is necessary, as hard as 6H, and the point must be kept well sharpened.

There are two general rules of action in producing a drawing which give the answer to the question which oftenest confronts the beginner: "What is to be done first?" or "What is to be done next?" These rules are:

1. Draw everything that is positively known.
2. Work from the inside to the outside.

Every problem has some positive data, assumed or calculated, to start with. The first thing to do in every case is to get this data represented by lines on the paper. An expert designer has been heard to say that until he had spoiled the blankness of his sheet of paper by some lines, he could not design. There is something in this; and almost invariably the first line to draw is a horizontal center line somewhere near the middle of the sheet; draw it! Draw it at once without hesitation, and the layout is begun. We now have something about which to build.

In this case the designer would first calculate the size of the piston rod, and determine the fastening to the piston. He would then draw the rod and build a hub around it. He would next calculate the width or thickness of piston and size of packing rings, and draw the two vertical lines 5 inches apart, to indicate the piston faces. These lines would be limited by the cylinder bore, which he knows to be 16 inches; hence horizontal lines 16

inches apart, parallel to and symmetrical with the center line, are the next to be drawn. Short vertical lines indicate the location of the packing rings. As the nominal travel of the piston is to be 12 inches, the location of the piston and rings can be shown on both sides of the central vertical line at the limits of travel. A clearance must exist between the heads and the piston (in this case $\frac{1}{4}$ inch is allowed), hence the lines of the heads can be drawn, and the general inside outline of the cylinder barrel is complete.

This is all in direct application of the foregoing rules, and is so simple, natural and direct that it hardly requires such explicit statement. We have simply taken such data as we had and put it on paper, placing it where it can be seen from all sides, and where the mind is relieved of the labor of carrying it.

If the student will only appreciate this one rule and draw all he knows about the problem, he is well on his way to its solution. *Draw everything you know, and work for what you don't know*, is what these two rules say, and the first question to arise should be: "Have I drawn everything that is known about the problem?" before he asks himself or any one else: "What shall I do next?"

One other rule might be added to these two: *Keep dimensions in even figures, if possible*. This means that small fractions should be avoided. It is just as easy to bear this point in mind, and save the workman much annoyance and chance of error, as it is to disregard this matter. Even figures constitute one of the trade-marks of an expert draftsman. Of course a few small fractions, and sometimes decimals, will be necessary. Remember, however, that fractions must in every case be according to the common scale; that is, in sixteenths, thirty-seconds, sixty-fourths, etc.; never in thirds, fifths, sevenths, or such as do not occur on the common machinist's scale.

A systematic, definite mode of treatment on these lines must become a habit, so that all problems, however complicated, can be approached with confidence in the same way. It is the drawing of one line which makes clear the drawing of the next and subsequent lines; and the most serious obstacle which the student is likely to set for himself is trying to see the whole problem through from the beginning. Even an expert cannot do this, but allows the layout to develop results as he proceeds.

The details of the piston and rod being given in Plate E, the foregoing work is very easy for the student. The thickness of the barrel and heads being determined ($\frac{1}{8}$ inch in this case), the exterior outline may be partially drawn. The fixed head at the yoke end must be thicker than this, in order to receive the yoke and stuffing-box bolts without breaking through. The recesses or counterbores at either end of the cylinder should be so located that the packing rings run over the edge a little at the end of the stroke, thus preventing the wearing of a shoulder by the piston stopping in the same place every time. The counterbore should be deep enough to allow reboring the cylinder without the counterbore being touched by the tool. In this way the counterbore is retained to center the cylinder at its original location.

The size of steam ports having been calculated, they may be drawn in, the turns being made easy and as direct as possible. The height to valve seat must be kept at the lowest limit consistent with sufficient metal between and outside of the ports. As the detail of the ports might be somewhat troublesome, it is shown in an enlarged sketch for the student's benefit. Chipping or filing strips $\frac{1}{8}$ inch high are left on the port edges, which must be true, in order to finish them up easily.

The three inner ports are for exhaust, the outer ones for admission of steam. This five-ported cylinder is peculiar to the direct acting steam pump, it being a device to effect the cushioning of the piston at the end of the stroke, thus preventing the piston from striking the heads. This is necessary, since no positive limit of motion exists, as is the case in machines with crank and connecting rod.

When the edge of the piston has passed the outer edge of the exhaust port, as shown in Fig. 1, the steam, which has been exhausting through port A, is confined in space B and port C, and, being compressed by the piston, acts like a spring to retard its motion. If the point P is properly determined for a given speed, the piston will always compress the steam just enough to cause it to stop at the end of the nominal stroke; in this case, $\frac{1}{4}$ inch from the head. It is evident, however, that at different speeds the piston will have more or less power to compress the steam, and will not stop at the point desired. This causes the trouble of "short stroke," and

consequent inability to make the pump work to its full capacity. Now if we connect ports A and C by a small opening shown dotted at D, and control this opening by a plug valve operated by hand from the outside, we can let a little steam leak by into port A, thus reducing the cushion and allowing full stroke.

In order to avoid complicating the drawing, no cushion valves are shown or required to be put on by the student. They are not customary in small pumps, but might advantageously be put on the present illustration.

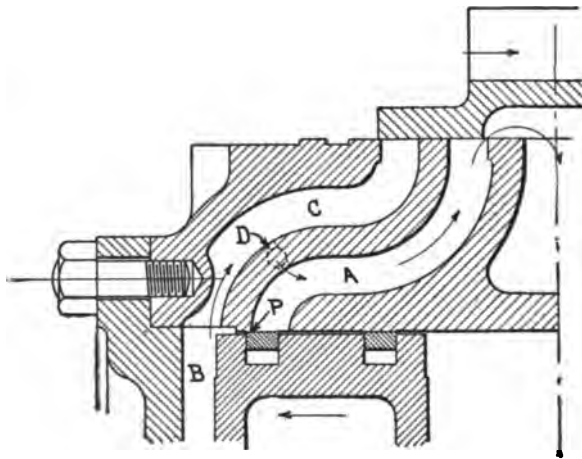


Fig. 1.

The valve seat must be a scraped surface, while the chest face need not be; hence the latter is finished $\frac{1}{8}$ inch lower. This also gives a ledge against which the steam chest fits, thus securing positive location.

The bolting of the heads and the steam chest should allow a width of packing inside of the bolts of $\frac{1}{2}$ to $\frac{5}{8}$ inch, otherwise there is danger of the steam blowing out the packing and causing leakage around the bolts. The bolts do not fill the holes, the latter being drilled large, from $\frac{1}{16}$ to $\frac{1}{8}$ inch. The spacing, if wider than 5 or 6 inches, is likely to permit springing of the flanges between the bolts, and consequent leakage. Bolts less than $\frac{5}{8}$ inch diameter are not desirable, as they can be easily twisted off with an

ordinary wrench. In this case the cylinder head takes $\frac{1}{4}$ -inch bolts, the yoke, stuffing-box and gland, $\frac{3}{4}$ -inch.

The flanges of heads and cylinders are usually from 25 per cent to 50 per cent thicker than the body of the casting.

Drips, $\frac{3}{8}$ -inch pipe tap, to be fitted with cocks, are necessary at both ends of the cylinder to readily drain the cylinder of water.

Molding of Steam Cylinder. The design is often influenced by the way in which the piece is to be cast. It often takes but a slight change of design to save many dollars in pattern making and foundry work. Hence the habit should be formed of always judging the design of a piece from the foundry standpoint. In this case it is evident that the ports and cylinder bore must be cored out, and the most obvious position of molding is to lay the cylinder on its side, the parting line of the flask being along a vertical plane running lengthwise through the middle of the cylinder. This permits the chest flanges to draw nicely, likewise the ribs on the foot, and allows the thin curving port cores to stand edgewise in the mold.

Another method of molding would be with the valve seat down. This would involve loose pieces for the chest flanges, and setting of cores for the cylinder foot. It would, however, assure sound metal beyond question at the valve seat. Spongy metal at the important wearing surfaces, the valve seat and cylinder bore, is not permissible in any case, and care in molding, and good design, is necessary for good results.

All corners must be carefully filleted, and chunks of metal must be avoided, especially where several walls or ribs join. The metal must be kept of average uniform thickness, so that the whole casting will cool uniformly.

Machining of Steam Cylinder. The boring may be done on a vertical boring mill, the heavy arm carrying the tool being thrust down unsupported into the cylinder, the latter being rotated by the table to which it is clamped. If the horizontal boring machine be used, the hole through the inside head for the stuffing box must be large enough to permit a stiff boring bar to be passed through. This allows a support at each end of the bar, to take the strain of the cut.

The plane surfaces may be finished on a reciprocating planer

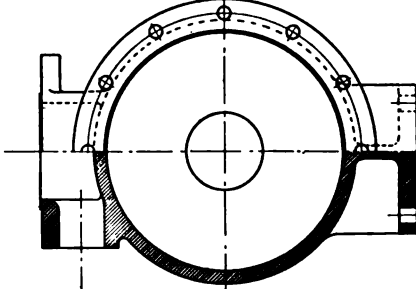
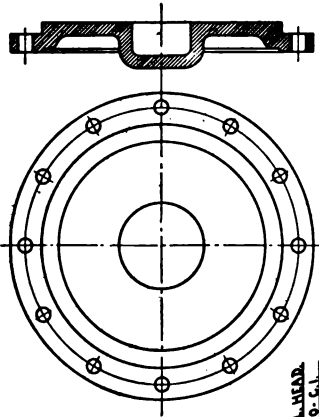
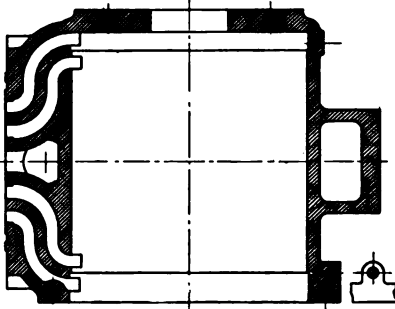
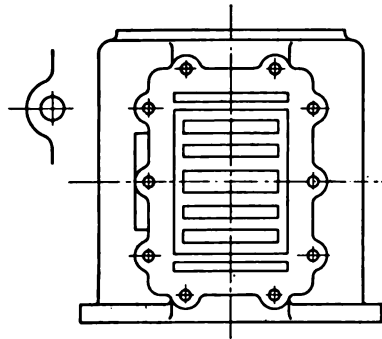
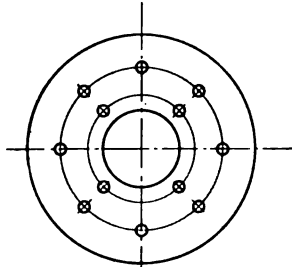
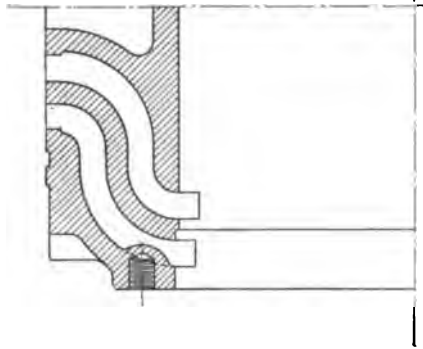
or a rotary planer. In the latter case it is desirable to keep all lugs or projections back from finished surfaces, to permit the large round head which carries the cutters to pass over them without interference.

The drilling of standard machine parts of this character is usually done through jigs, or plates carrying hardened steel bushings laid out to correspond with the holes required, and through which the drill is guided. These plates are located by some fixed line or lug on the casting, and then clamped fast, thus assuring exact duplication and rapid drilling, and avoiding the tedious laying out of the holes. In order to save changing the drill it is desirable, if possible, to maintain the same size of hole on any given surface. Of course it is not always admissible to do this.

Plate G. Steam Cylinder. After the exact and complete development of the steam-end layout, the student should be pretty thoroughly acquainted with the details of the cylinder. All the work thus far has been entirely for *his own* information, to get his ideas in visible shape, so that he himself can have a permanent record of them. This layout, however, is not in suitable form to finish up into a detail drawing. Its sketchy nature and the confusion of parts, especially if attempt were made to add dimensions, would render it somewhat difficult to be read by a workman taking it up as an unfamiliar subject. Hence it is now necessary to separately detail the parts, with the object in view of transferring, in the simplest and most direct manner, specific information to the workman which will enable him to construct the several parts. It is not enough now that the drawing be clear to the man who makes it; it must be clear, *absolutely clear*, to the shop mechanic, who has no means of knowing the designer's plans except through the information which the drawing gives on its face.

This requires that the draftsman should put himself in the workman's place, and forestall, by the explicit nature of his drawing, all possible questions which may arise in the shop. In this way only can he hope to avoid errors of construction and the continual annoyance of endless explanation of his orders.

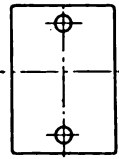
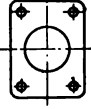
Plate G is to be a finished drawing, and the first thing to do is to lay out the sheet. The standard sheet for details which has



STEAM CYLINDER
16-52-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE
BOSTON-MASS.
SCALE: 1/2"=1"

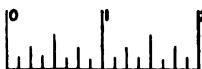
STEAM CYL.
CORRESPONDENCE

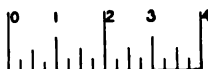
CYL. HEAD
END VIEW



been adopted is 18×24 inches trimming size, with $\frac{1}{2}$ inch margin all round, so that the working space is 17×23 inches. The rectangle for the title is to be laid off $2\frac{1}{2} \times 4$ inches in the lower right-hand corner, and must never be altered, either in size or position. This does not mean that other sizes are wrong, but once a standard system is adopted it must be strictly adhered to, both for artistic and commercial reasons. The scale to which the drawing is to be made is indicated in the title corner on every plate.

The scales permissible for shop drawings in the United States are those readily derived from the common foot rule, such as full size, 6 inches = 1 foot, 3 inches = 1 foot, $1\frac{1}{2}$ inches = 1 foot. These are the most common, most easily read from an ordinary scale, and one of these can usually be adopted. The student should learn to read these from an ordinary scale without being confined to a special graduation. To do this it is not necessary to divide each dimension by 2, 4 and 8 to get half size, quarter size, or eighth size, and then lay down the result. For half size, or 6 inches = 1 foot, $\frac{1}{2}$ inch on an ordinary rule represents 1 inch. Hence, each half inch may be read as 1 inch, and

its subdivisions accordingly, thus:  For 3 inches

= 1 foot, or quarter size, $\frac{1}{4}$ inch represents 1 inch, and looks thus:  For $1\frac{1}{2}$ inches = 1 foot, or eighth size,

$\frac{1}{8}$ inch represents 1 foot, and looks thus:  It

is very easy to get accustomed to this, and it saves much time and trouble hunting up a special scale every time.

The other allowable scales, less common, but sometimes necessary on large work, are 1 inch = 1 foot, $\frac{3}{4}$ inch = 1 foot, $\frac{1}{2}$ inch = 1 foot, $\frac{3}{8}$ inch = 1 foot, $\frac{1}{4}$ inch = 1 foot, and $\frac{1}{8}$ inch = 1 foot. To use these scales conveniently, special graduation is desirable.

The general arrangement of the sheet, number of views and approximate space occupied, should be blocked out first. This can easily be done from the original layout. In general, several cross-

sections are preferable to a single view, which involves many dotted lines. Dotted lines are very convenient for showing invisible parts of an object, but they are often abused, and the drawing of a complicated piece made indefinite and confused thereby. As already stated, a working shop drawing is solely to convey information to the workman at the least possible cost. A careful consideration of this will settle the question of the number of views necessary, their character, and the amount of dotted line work desirable.

Never let the drawing become the master; always be master of the drawing. Do not draw an extra view if no use can be seen for it. Do not put in dotted lines if the detail is completely shown without them. Full lines, or lines which show visible portions must, of course, be shown completely.

The nature of the pencil work on Plate G should be the same as on the original layout; viz., sharp, definite lines and positive intersections. Above all things learn the habit of accurate workmanship, for it will save many errors and a vast amount of time. The draftsman must check himself at every line he draws. Slight errors in scaling will often throw parts out of proper relation to each other, and interferences, which the drawing does not show, will become apparent only when the parts get into the machinist's hands.

It is dangerous practice to project across from one view to the other. It only takes a slight irregularity or spring in the T-square to vary the location of lines very perceptibly from where they should be, and once out of scale from this reason it is almost impossible to work a view with any certainty. Rather than project across from view to view, the principal lines, at least, should be scaled off on each view, and it will be found that in the end time will be saved and greater accuracy secured.

It is not economical of time to finish one view before beginning another. It is better to take some single detail of the drawing and develop it in all views, in order to study it from all sides. What is completed in one view may be found to be totally wrong when developed from another side, and the time spent on the first view will be wholly wasted. For example, in the present case the steam ports should be drawn in side elevation, and eleva-

tion and plan, and when thus completed the mind can leave them and in a similar fashion take up the study of the flanges, then the cylinder foot, and so on. Thus again the draftsman is master of his drawing, for he is continually making it tell him whether he is right or wrong. If, on the contrary, he allows himself to look at but one side at a time, and works from that standpoint alone, it may lead him into many difficulties from which he cannot readily extricate himself.

Do not be afraid to use the eraser. The draftsman who hesitates to draw until he is positive that no change will be necessary, is likely to spend the greater portion of his time in unprofitable dreams, for he is attempting the impossible. A drawing is a means, not an end; and, as has been already pointed out, it greatly assists the draftsman in clearing up many doubtful questions which the imagination alone cannot do.

A bold attack of a problem shows the quickest path to its solution, even if lines must be erased again and again. It is a sign of serious lack of ability to hesitate in the use of pencil and eraser.

Attention is called to the simple, straightforward character of Plate G. Notice the almost entire absence of dotted lines; the enlarged section through the ports, giving ample opportunity for dimensions without confusion; the use of a half end elevation and a half cross-section,—the one to make clear the flange and bolt layout; the other to show the exhaust opening, the small auxiliary views (drawn at convenient points) of the exhaust flange layout, the cylinder foot and the drip boss.

A steam cylinder is a fairly complicated casting; and it would be an easy matter, by the use of elaborate views, the dotting in of parts already completely shown, and careless line work, to rob this drawing almost entirely of its clearness and directness of illustration. *Just what is necessary* (for clearness' sake) *and no more* (for cheapness' sake), is the whole matter in a nutshell, and is what determines its shop and commercial value.

Dimensions and Letters. A good line drawing can be spoiled by poorly arranged dimensions and hasty lettering. The five principal points to be kept in mind to develop excellence in this respect are:

- (1) System.
- (2) Accuracy.
- (3) Clearness.
- (4) Completeness.
- (5) Character.

System. The habit of system in placing figures and letters on a drawing is the one element which, to a large extent, controls all the others. If the systematic habit is established early, the other requirements will be fulfilled more easily. A haphazard method will, on the contrary, just as surely prevent the successful cultivation of the ability to figure a drawing. In fact, if the haphazard habit is continued it will itself, by the dissatisfaction which it causes, soon compel the draftsman to change his occupation.

In the first place, whatever part of a machine detail is to be dimensioned, that particular part should receive attention until it has been completely figured. Do not jump from one point to another, putting in a figure here and another there. Stick to one thing until it is done.

For example, take Plate F and the simple detail of the steam pipe. Suppose we start with one of the square flanges. The first question is: "Where is this flange located?" This is answered by the dimensions 5 inches and 12-inch centers, which refer the face of the flange to the center of the pipe and the flanges to each other. The next question is: "What are the three dimensions of the flange,—length, breadth and thickness?" This is readily answered as shown on the drawing. The next question is: "What further description is necessary to completely specify the shape of the flange?" This is answered by the radius of the corners, $\frac{3}{4}$ inch R. Next, "What drilling or special feature exists in the flange?" This is answered by $\frac{1}{16}$ -inch drill, $3\frac{1}{2}$ -inch centers, and the letter *f* to denote that the face is to be finished.

The round flange of this pipe is approached and figured in the same way, except that the location of the face is preferably referred to the face of the square flange by the figure $8\frac{1}{4}$ inches, instead of to the center of the pipe, because the planer hand will more naturally use this figure.

These flanges are now to be connected by a pipe involving two sizes. The main pipe is 3 inches diameter inside, 4 inches outside, and $\frac{1}{2}$ inch thick, running into the two branches by fillets

and radii, as figured. The two branches are really one pipe, $2\frac{1}{2}$ inches inside, $3\frac{1}{2}$ inches outside, $\frac{1}{2}$ inch thick, and sweeping down into the square flanges by 4-inch radius.

This systematic method takes longer to explain than to actually execute, but it is typical of the train of thought which must be followed on all pieces, simple or complicated, in order to properly place dimensions.

In general, it may be stated that all parts of a piece must be referred either to each other, or to some common reference line, or to both. Each part so referred must then be figured as a piece by itself, and then its connections to the principal structure. Thus, figuring a machine detail involves three things:

- (1) Relative location of its parts.
- (2) Proportions of these parts.
- (3) Proportions of connecting members.

As in the original design of a piece so in the figuring of it, the draftsman must as far as possible put himself in the place of the workman, judging the methods and processes of construction and available tools. This will largely influence the arrangement of the dimensions. Of course it implies considerable experience in shop work, which some students do not possess. He can begin none too early, however, to learn to look at his work from the shop standpoint, and surely make it some better on that account.

Pieces must not only be systematically dimensioned, but regularly specified and called for by suitable titles.

A title should specify at least three things:

- (1) Name of piece.
- (2) Number wanted for one machine.
- (3) Material.

To these might be added a fourth; viz., pattern or piece number. The latter is not specified on the drawings under discussion, because systems of pattern and piece numbering are so varied that little would be gained by developing one for this special study.

These titles should always be put on in the same way, as the workmen become used to a certain system and are likely to misunderstand directions if a regular plan is not followed. A good way to arrange titles is suggested on the plates, although there are others which might be used.

Bolts are usually specified by diameter and length under the head, the length of thread being to some standard system in use by the shop, unless otherwise called for. Bolts are specified on the sheet containing the piece into which they are tapped. In the case of through bolts, tapped into neither piece, they are preferably called for in connection with the principal member.

Accuracy. Of course the dimensions on a drawing must be accurate. It is, however, a very easy matter to make errors. To insure accuracy a figure must *never* be put down carelessly, and a constant watch must be kept that scaled figures add up to over-all dimensions. It will not do to rely on scaling alone, as a very slight variation from exact scale may throw two dimensions out with each other. In spite of all the care that can be exercised errors will creep in, and a final thorough checking must be given a drawing before it is pronounced complete. A good rule to follow in checking up is to "assume everything wrong until it is proved to be right."

Clearness. As in the line drawing itself, there must be absolute clearness of instruction by the dimensions. Any doubt as to what a figure is, or what it means, rules out that figure as part of the drawing. If a piece is made wrong because doubt of this character is transmitted to the workman, the draftsman is always held responsible for the error.

Figures should, in all cases, be placed where they can be most clearly read. They should be bunched on a single view as far as possible, but not when greater clearness demands that another view be used. It hinders the reading of a drawing materially if the eye is forced to jump over large spaces of the sheet from view to view, to catch the several dimensions of a small detail. Usually it is easy to so group figures as to avoid this.

It is a good plan to keep dimensions off the body of the drawing, when it can be done so conveniently. It is not worth while, however, to go out of one's way to do this, as figures in the open spaces of a detail do not at all destroy its clearness.

Extended notes on a drawing to make it clear should not be required, but they should be used without hesitation if any doubt exists. An explicit note of instruction is the final resource for clearness when the art of drawing fails of its purpose, as it sometimes does.

Completeness. A detail is completely dimensioned when it shows *all* the figures necessary for the workman. Anything short of this is incompleteness. As modern shops hold the draftsman solely responsible for the design, the mechanic is not allowed to modify it by filling in any omitted dimensions. The only way to be sure that all the dimensions are on is to systematically go all round a piece inside and out, according to the method suggested under the paragraph on "System."

It is a good plan to always bear in mind that not only the machinist is to use the drawing, but also the pattern maker. For the benefit of the latter, special attention is desirable in figuring the cores. This saves him some addition and subtraction. In general, it has been found that less chance of error exists if mathematical work is not required of the shopman, all necessary data being furnished on the face of the drawing.

Character. By character in figures and letters is meant uniform style, height and slope, and a certain boldness peculiar to the work of the expert draftsman. The last is difficult for the novice to acquire. The student should not be discouraged because his efforts do not look like impressions from printers' type. Artistic excellence is the result of long experience, but is based on character. If the student can once get character into his work, the artistic feature will, with careful and constant practice, gradually develop. It is safe to say that there is no one element of a drawing which more positively stamps it as the work of an amateur than the character of the lettering, and every attention should be paid to getting out of the apprenticeship stage in this respect. Freehand lettering only is permitted in the drawings illustrated herewith. Ruled letters are seldom found on any working drawings, as the element of time involved is so great that few shops are willing to pay for it.

Uniform style requires that if capitals only are used in titles, they only must be used in notes and elsewhere on the drawing. If lower-case letters are used, they must be used in every part of the drawing. One style should not be mixed with another. The height of the letters should be limited by two horizontal lines, and though practice may render the upper line unnecessary, it takes but an instant to draw it, and uniform height is then assured. A good

height for titles of details such as are illustrated is $\frac{5}{8}$ inch. The height once chosen should be adhered to throughout the whole set. A medium, not a hard, grade of pencil (3H) will give the hand greater freedom. A great temptation exists to omit titles from the pencil drawing, simply inking them on the tracing. This is false economy of time, for in the end it will be found that enough time will be saved by the certainty with which the tracing can be made to more than pay for the labor on the pencil drawing. Again, it permits the tracing, in regular shop practice, to be made by cheaper labor than that which produced the pencil drawing.

Uniform slope is most easily acquired by the use of guide lines put in at frequent intervals. A small wooden triangle can be made, giving the required angle. The angle of the letters shown on the plates is 9 degrees, or about 1 inch slope in 6 inches. The question as to whether letters should incline backwards, forwards, or stand vertical, does not enter this discussion. Character is not affected by the slope. The student may choose whatever comes most natural to him, but having chosen, the character of his work will be spoiled if he varies it. The most difficult of the three is the vertical style; hence most draftsmen incline their letters. The backward slope is used on the plates of this Instruction Paper, thus giving the student opportunity to compare with plates in the earlier books, and follow his preference.

The effect of change of style, height and slope is shown in Figs. 2, 3 and 4, respectively. Attention is called to Fig. 5, which is a sample title, in which these points are corrected.

Principal Titles. The principal title of a drawing should contain at least seven items:

- (1) Name of principal details shown.
- (2) Name of machine.
- (3) Firm name and location.
- (4) Scale of drawing.
- (5) Date of completion.
- (6) Draftsman's signature.
- (7) Filing number.

To these are often added others, but for purposes of filing and reference the above at least *must* be put on. The filing number may or may not be put in the title frame, but it is really a part of it. It is often put in the margin below the title.

An arrangement of title should be established and then followed exactly, without variation either as to location on sheet or detail make-up. Abbreviated words are always permissible in titles, provided the meaning is clear. Special care must be taken in punctuation, however, as a title, whether abbreviated or not, has an unfinished appearance if the periods, commas and other necessary punctuation marks are not included.

STEAM CYLINDER.
16-8½-12 Duplex Pump.

Fig. 2.

STEAM CYLINDER.
16-8½-12 DUPLEX PUMP

Fig. 3.

STEAM CYLINDER.
16-8½-12 DUPLEX PUMP

Fig. 4.

The sample title illustrated in Fig. 5 indicates the arrangement chosen for the drawings of Part VI. Note that it is necessary in this special case to add an extra subject to the seven given above; viz., the residence of the student draftsman.

This style of title must be put with care on every drawing, even on the rough pencil layouts. In the latter case it may of course be left in pencil, as the rough layouts are not to be inked.

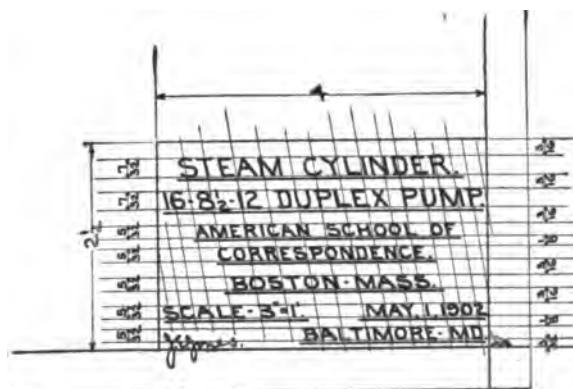


Fig. 5.

Inking and Tracing. Both bond paper and tracing cloth are used in business practice for finished drawings. It is desirable to

keep a stock of both in any drawing office, so that either may be used as occasion requires. Bond paper stretched on the board gives a beautiful surface to take the ink, and very handsome and effective detail or assembled drawings can thus be produced.

Changes are not quite as readily made on bond paper as on tracing cloth, and it takes a little longer to make the blue print. In other ways the bond paper is not quite as flexible to use as the tracing cloth. However, one must be guided entirely by shop conditions to settle the question of preference. As the tracing cloth is generally used, and suits the purpose of the student better, it will be required in this work.

The inking should be done on the *rough* side of the cloth. One reason for choosing this side is that as the cloth tends to curl under toward the glazed side, the drawing as it lies right side up will tend to straighten itself. This seems to be a small point, but it is a very important advantage for filing and for the convenience of those who are to handle the drawings. Also the rough side takes colors and inks better than the glazed side. To trace on the glazed side is not wrong, for it is often done, but it possesses no advantages of its own, and has the disadvantage mentioned above.

Chalk dust scattered over the surface of the cloth after it is tacked down will remove the slightly greasy coating which prevents the ink from flowing well from the pen. This is always necessary if the glazed side be used, and usually for the rough side. The chalk must be carefully removed from the cloth before inking.

The first step in inking is to draw the center lines. Remember that *accurate intersections* are of the utmost importance. No circle is complete without two intersecting lines, preferably at 90 degrees, to determine its center, and these lines should be inked before the circle. When this is done a definite point exists for the needle point of the compasses. If the circle is drawn first the needle point may not be placed accurately at the center on the pencil drawing beneath, and the location be thrown out.

Likewise the principal center lines of pieces, the lines around which the pencil drawing was built up, should be at once put in.

The main body of the drawing, the full lines, should be taken *next*. In general, circles and arcs should be inked first, but there

are cases where it is easier to run the arcs into the straight lines than to match the straight lines to the arcs. They are exceptions, however, and can be judged only as the case arises.

Straight lines, horizontal and vertical, should be inked with the T-square and triangle *in position*. It is a common practice to dispense with the use of the T-square entirely in inking in, using the triangle to match the lines to the arcs already drawn. A necessity for this implies very poor work on the arcs, for with any reasonable care true horizontal and vertical lines will match the arcs all right. With regard to time required, the accuracy with which the T-square may be brought up to a line, or the triangle set on the T-square, more than makes up for the time gained in even an approximate setting of the triangle without a guide. It is just as easy to cultivate the habit of holding the T-square and triangle with the left hand and the pen with the right, and draw an exact line, as to lapse into the other method, which is not workmanlike.

The lines of the body of the drawing depend for their width upon the size of the detail. For a large piece they may be $\frac{1}{32}$ inch wide, and the shade lines $\frac{3}{64}$ inch. For a small detail such widths would be too great. Remember that *contrast* is the principal aim, and to produce it is the only reason why we use different kinds of lines on a drawing. Hence the greatest care must be exercised to prevent body lines from becoming confused with center or dimension lines, and *vice versa*. Also thick lines are desirable for the production of a bold blue-print.

Shade lines are shown on Plates I, K and N only. They are put on according to principles already explained. They certainly improve the drawing from an artistic standpoint, and the student should know how to put them on when desired. Whether or not it is desirable to adopt them on all working drawings is not the purpose of this book to decide, or even discuss. Almost always drawings can be made perfectly clear without them, and are so made and satisfactorily used in probably the majority of shops. Some shops are willing to pay for the extra time necessary to put on shade lines; this, however, is purely their own investment.

Cross-section lines are usually drawn at an angle of 45 degrees with the horizontal, and on sections which are adjacent

to each other the slope should be in different directions. If three or more sections come together the width between section lines can be so changed as to indicate clearly the different parts. An example of this is shown in Fig. 6.

The spacing of section lines must not be too fine, rarely closer than $\frac{1}{16}$ inch, more often from $\frac{3}{32}$ to $\frac{1}{8}$ inch, else the labor involved is too great and uniformity practically impossible. It is a waste of time to rule in section lines on the pencil drawing; they may be sketched in freehand, as shown on the original layout of the steam cylinder. Even spacing concerns the tracing alone, and the student should train his eye to regularity as he traces. The thickness of section lines may be intermediate between that of center lines and body lines of the drawing.

Inking Dimensions and Letters. Extension lines may be dotted, as explained in Part IV, or they may be fine, full lines, the latter method being illustrated in the plates of this Instruction Paper. Dimension lines are also often made fine, full lines. If these lines are made full they should be made as fine as it is possible to draw them and still have them firm, clear lines. The same width should be used as for center lines.

Character in inked figures and letters is more difficult to attain than in pencil work. In the first place a pen suitable to the style of drawing is necessary. A civil engineer's fine mapping pen, which gives character to his drawing, is not desirable in producing the bold character of a machine drawing. For the latter choose a rather stiff, blunt pen which is not "scratchy," but runs smoothly, making a line of uniform width. A pen with a round, or ball-shaped nib, recently put on the market, answers the purpose well for ordinary details. A bold, free stroke should be made with the idea of producing a smooth, even line, finished

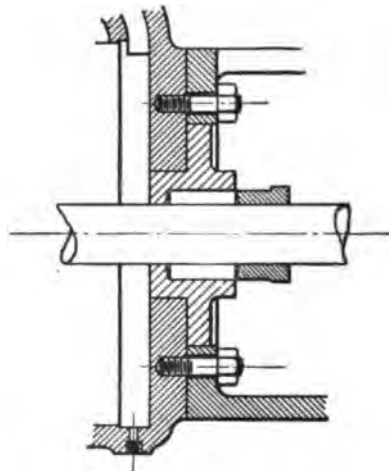


Fig. 6.

at the first trial. The hesitating uncertainty of the beginner's hand produces a "shaky" letter, and going over a letter or figure twice or more to smooth it up usually makes it worse.

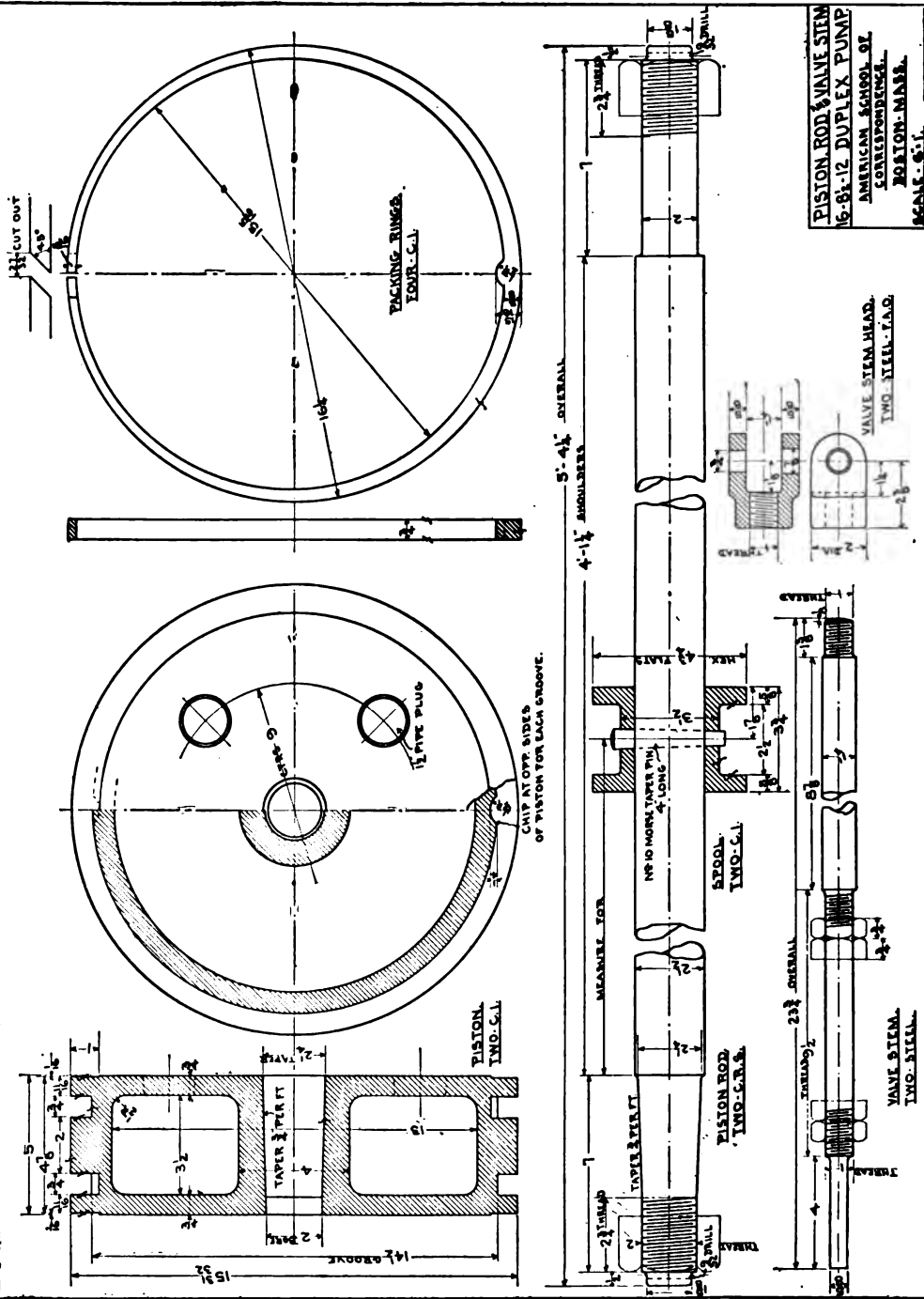
Figures and letters which are broad in proportion to height are easier to make, and have more character. It should never for a moment be forgotten that uniform *height* and *slope* carefully followed will develop character and quickly lead to artistic excellence.

Foot and inch marks are often put after figures according to the common usage. In cases where feet and inches are expressed, thus: 3' — 6", or 4' — 0", they are, of course, absolutely necessary, and the dash between the figures must be very positively indicated. In cases of inch dimensions alone the marks may be put on if desired, but where there can be no doubt that inches, and not feet, are meant, the inch marks are not necessary. This practice is followed on the plates of this Instruction Paper.

Abbreviations. A list of the most common abbreviations in use on working drawings follows. This list has been adopted for the plates in Part VI:

F. A. O.	finished all over.
f.	finished surface.
R.	radius.
D.	diameter.
R. H.	right hand.
L. H.	left hand.
P. R.	piston rod.
P. TAP.	pipe tap.
CTRS.	centers.
C. I.	cast iron.
S. C.	steel casting.
Bz.	bronze.
C. R. S.	cold rolled steel.
T. S.	tool steel.
O. H. S.	open hearth steel.
W. I.	wrought iron.

Plate E. Piston Rod and Valve Stem. The piston is of the one-piece box type, with sprung-in rings. The width is reduced to $4\frac{7}{8}$ inches at the outside, so that if the piston strikes the cylinder heads it will not tend to spring and break off the narrow ridge of metal outside of the packing ring. The piston rod is fastened to the piston on a taper drawn in by a nut, and the



**PISTON, ROD & VALVE STEM
16-84-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE
BOSTON, MASS.
SCALE - 6"1.**

③

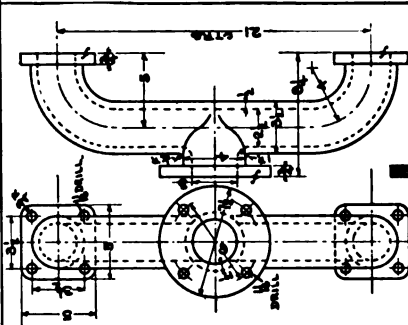
nut is checked by a $\frac{1}{4}$ -inch split pin. The packing rings are prevented from slipping round the piston by lugs fitting loosely in chipped recesses in the groove. These being at opposite sides for each groove, the leakage of steam through the split in the ring is minimized, for it must pass half way round the piston before it can pass through the split in the other ring. This is a simple, but fairly effective, device.

The packing rings are usually cast in the form of a cylinder of some length, turned to a diameter a little larger than the cylinder bore, cut off to the required width, and sufficient space cut out to permit being sprung in to the size of cylinder bore.

The location of the spool on the piston rod is not positively known, as the setting of the valve bracket may be slightly different from what the drawing calls for. Hence, instead of a dimension, the words "measure for" are put on, to indicate that the spool be located during the erection of the pump. The hexagonal flanges of the spool are convenient to hold the rod from turning while screwing on the piston and plunger nuts.

Molding and Machining. There are no special features connected with the molding and machining of parts on Plate E. The holes in the piston side walls are necessary to give supports for the core, the piston being cast on its side. These holes, after the core is cleaned out through them, are plugged as indicated.

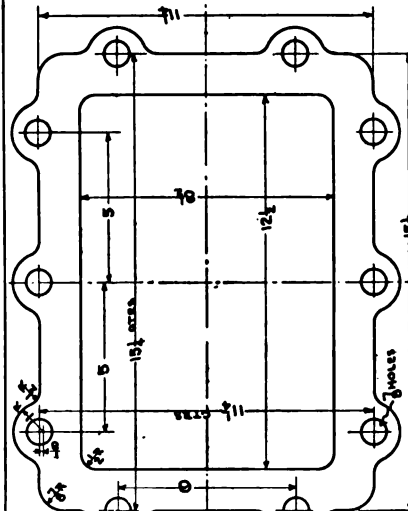
Plate F. Steam Chest and Valve. The steam chest in this instance is located on the cylinder by fitting down over the ledge made by the valve seat. The side flanges also serve the purpose of guiding the valve. It will be noticed that the steam chest cover is $15\frac{1}{4}$ inches $\times$ $11\frac{1}{4}$ inches, while the steam chest is 15 inches $\times$ 11 inches. This allows a ledge of $\frac{1}{8}$ inch, all around which the cover overhangs the walls of the chest. The steam cylinder flange in order to correspond must likewise be $15\frac{1}{4}$ inches $\times$ $11\frac{1}{4}$ inches. The reason this is done is because of the difficulty of making good matched joints between the cylinder flange, chest and cover. The practice of thus leaving a little ledge all round is by no means universal, and often the irregularity in the joints is smoothed off by chipping. This is the case with the other flanges on this pump. The steam chest, however, was thought less likely to match properly, and the slight overhang gives the finished appearance of a sort of beaded edge.



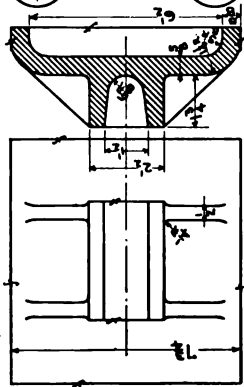
STEAM PIPE
ONE-P.L.



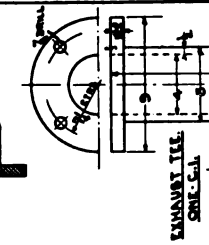
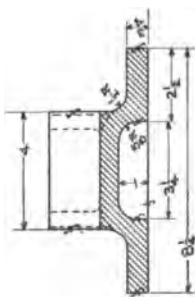
CHEST COVER
TWO-P.L.



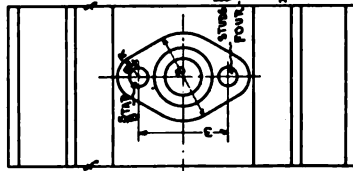
STEAM CHEST
TWO-P.L.



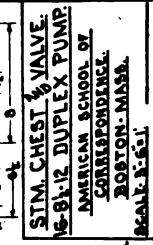
SLIDE VALVE
TWO-P.L.



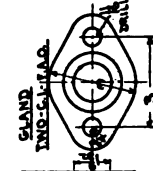
STEAM VALVE
ONE-P.L.



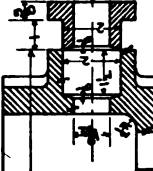
STEAM VALVE
ONE-P.L.



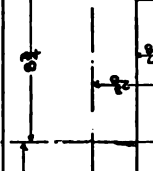
STEAM VALVE
ONE-P.L.



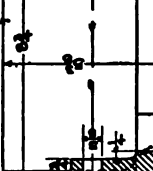
STEAM VALVE
ONE-P.L.



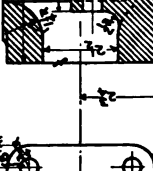
STEAM VALVE
ONE-P.L.



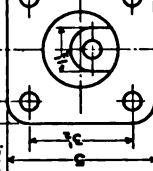
STEAM VALVE
ONE-P.L.



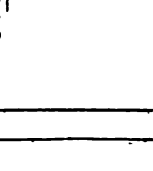
STEAM VALVE
ONE-P.L.



STEAM VALVE
ONE-P.L.



STEAM VALVE
ONE-P.L.



STEAM VALVE
ONE-P.L.

STEAM CHEST VALVE
16-81-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE
BOSTON, MASS.
SCALE 1/2"=1"

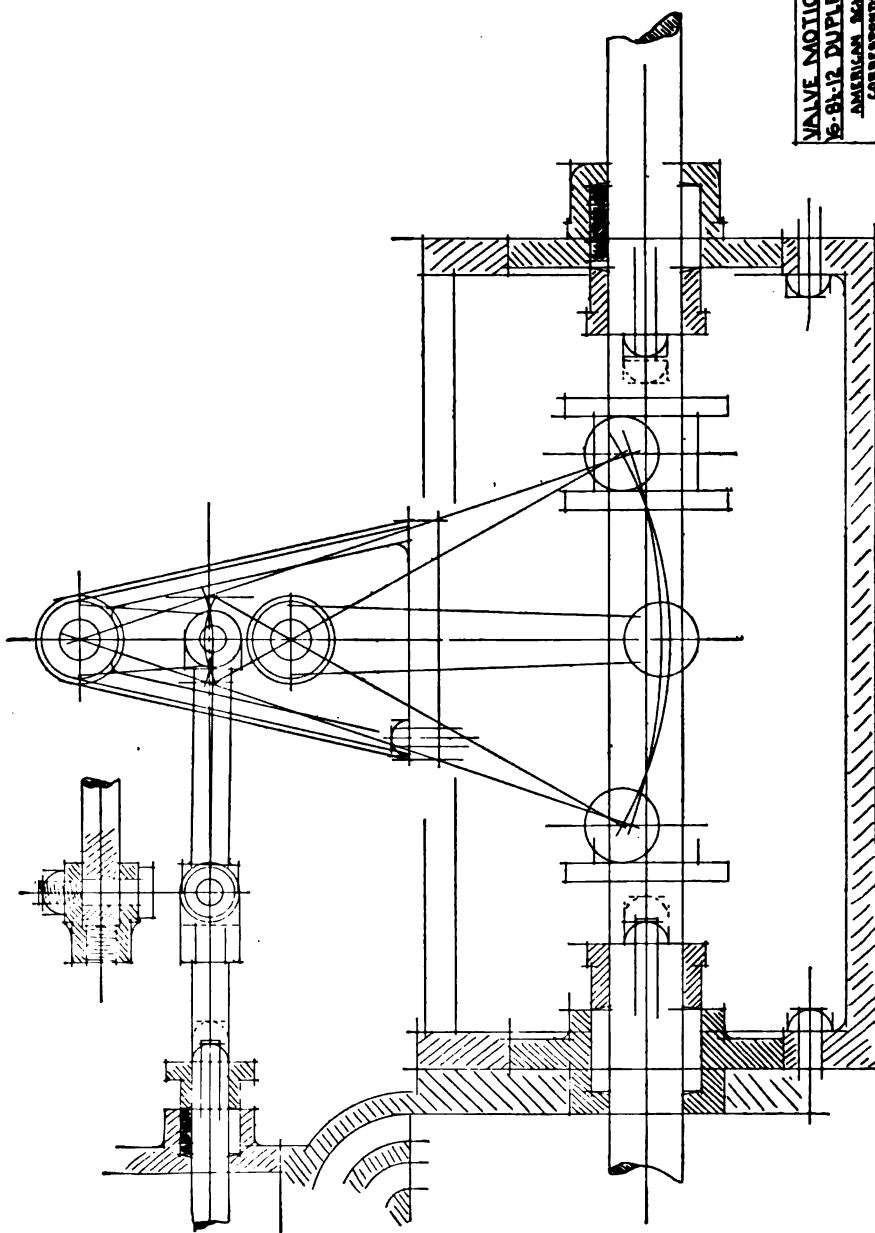
The valve is what is known as a "square" slide valve. This means that when the valve is placed central on the ports its working edges are "square" with the ports ; that is, in exact line with them. If the valve be moved either way from this position, the slightest travel will admit steam to one end of the cylinder and exhaust it from the other. (See Plate A.) Another way of stating this is to say that a "square" slide valve is a slide valve without "lap."

The valve is driven from the valve stem by the striking of the nuts against the lug on its top. Since the valve is already guided on its edges by the steam-chest flange, the valve stem, to avoid springing, must be perfectly free in the slot cast for it, as is shown by the $\frac{5}{8}$ -inch radius of the bottom, the stem being 1 inch in diameter.

The steam-pipe flange is made square to keep the height of the chest as low as possible. The radius of the bend should be ample ; in this case 4 inches is considered sufficient.

The exhaust tee must have its upper flange high enough so that the chest cover can be lifted and slipped off the studs without interfering with it. The lower flanges should be made wide enough to permit the tap bolts to be put in without striking the 4-inch vertical pipe, 5-inch centers being necessary. The $\frac{1}{4}$ -inch drip-cock, as located, readily drains the steam chest and exhaust passage of both cylinders, as well as the exhaust tee.

Molding. It is evident that the steam chest will be molded in the position shown on the drawing. The parting line of the mold will be through the centers of the steam-pipe opening and the stuffing-box. These holes must be cored out. The main body of the chest could be made to leave its own core, but it may not be made in this way. It may be cheaper to fashion the pattern solid, and make one large core-box for the inside. In this way the pattern will probably hold its shape better and require less repairs, than if it were made in green sand. The core-box will be an extra piece to make, but it probably will cost no more than to carve out the inside of the pattern, and is a rather more substantial job when done. The molding can be satisfactorily done by either method, shop conditions being the controlling element. As far as the labor of molding alone is concerned, the first method is probably easier, as it saves handling large cores.



VALVE MOTION LAYOUT
16-8-1/2 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE
BOSTON, MASS.
SCALE: 6"=1'

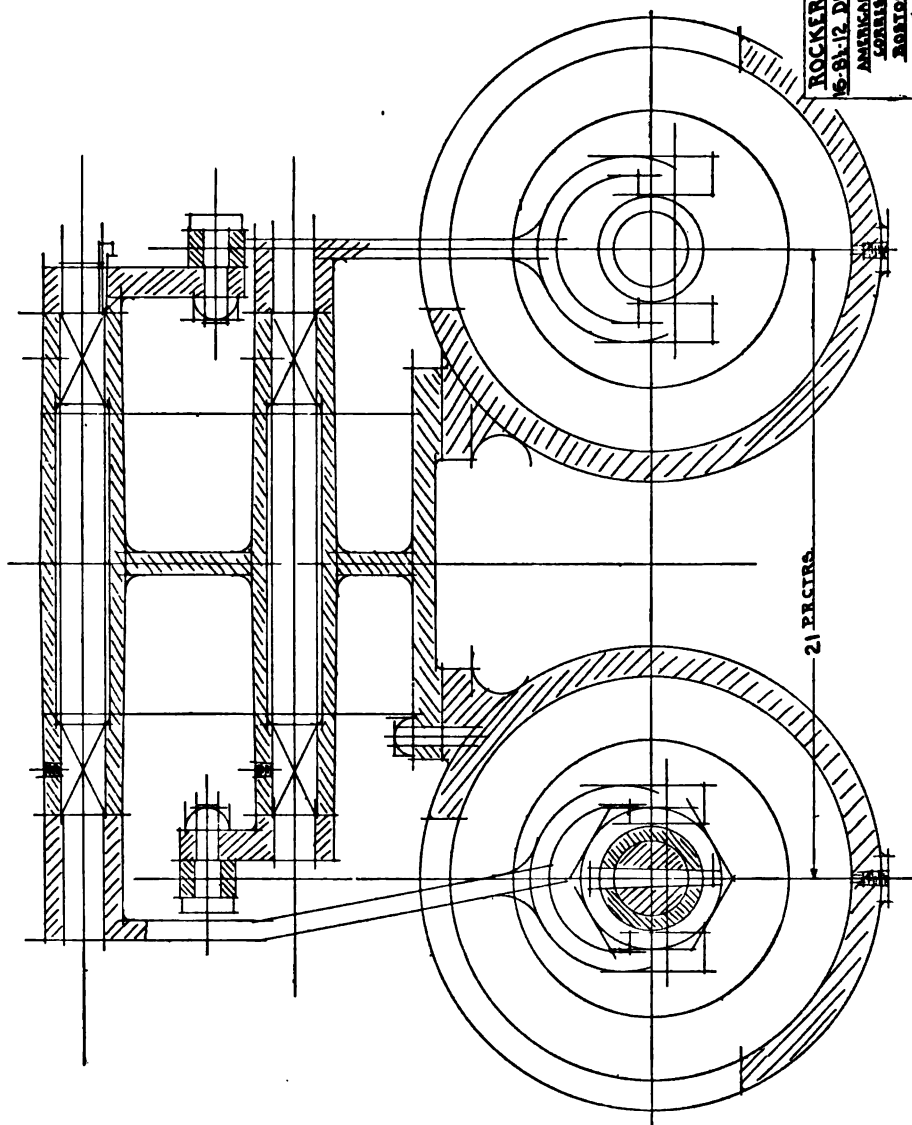
©

The other parts in Plate F are very simple in their molding, and require no special attention.

Machining. Most of the surface work on this plate is adapted to the planer. The slide valve may, perhaps, if finished in lots of considerable number, be more satisfactorily handled on the milling machine. The final finish of the face of the valve must be a scraped fit to its seat.

The drilling of the cover and pipe flanges is to actual layout on the casting, or preferably, through jig plates. A templet for laying out is at least desirable, even though the expense of a jig plate be not deemed necessary.

Plates C and D. Valve Motion Layout. These plates represent the layout of the valve motion, and are necessary in order to find the length of the levers and rocker arms. It will be noticed in Plate D that the valve stem of one side of the pump is controlled by the movement of the piston-rod of the other side, the proper direction of motion being given to the valve by placing the rocker shaft above or below the valve stem as required. By reference to Plate A it will be further noticed that the nuts on the valve stem inside the chest, which abut against the faces of the lug on the valve, do not rest against the faces of the lug in the position shown, but have considerable lost motion. This lost motion is one of the essential features of the valve motion of a duplex pump, and permits the valve to remain at rest for a short period at the end of the stroke, though the valve stem may have reversed its motion and begun its return stroke. When this lost motion is taken up by the movement of the stem and the nuts abut against the lug on the valve, the valve will move, and from this point to the end of the stroke be positively controlled by the motion of the stem. At the end of the stroke the stem will reverse, when the lost motion will again permit the valve to rest for the same period as at the other end, and then move on as before. The time of rest of the valve, and consequently the pistons and plungers, is approximately one-third the period of the stroke. This means that the piston on one side travels one-third of its stroke before it picks up, through the valve levers, the valve on the other side. During the second third of its travel it is bringing the



ROCKER ARM LAYOUT
16-84-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE
BOSTON, MASS.
SCALE: 6/1

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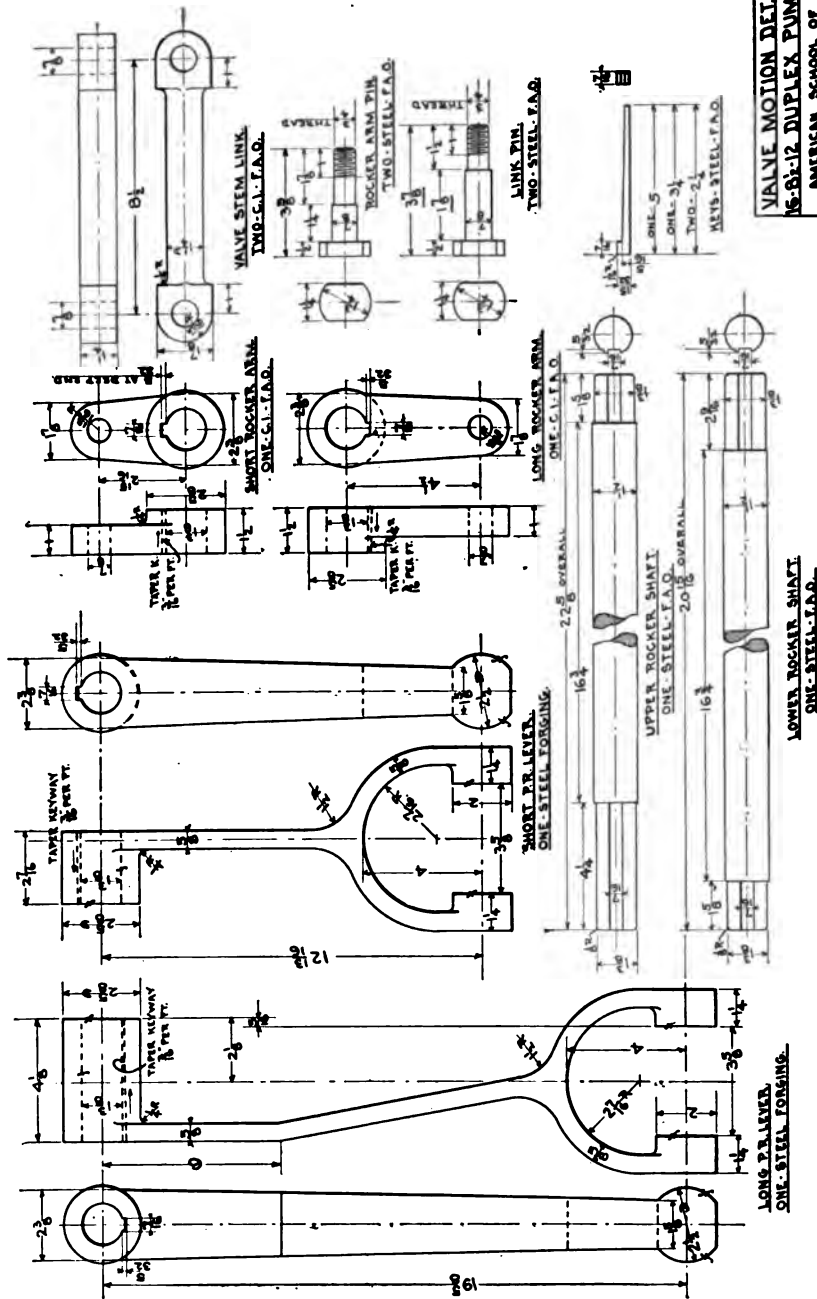
21 PCTRS

valve to the point of opening. During the last third of its travel it is opening the port, wider and wider, to steam. Thus the opposite piston will start when the first piston has covered two-thirds of its stroke, and there will be only one-third of the stroke when both pistons are moving at the same time.

This relative period of rest to motion is not always made in this exact ratio, but is at least approximate to it. The period of rest at the end of the stroke is to allow the water end to adjust itself quietly to the reversal of motion about to take place at the end of the stroke. When the plunger stops, the water valves must be given time to seat themselves, and the flow of water through the passages checked. It is much easier to start the flow in the opposite direction if the reversal of plunger motion is not instantaneous. Hence for handling long columns of water, which, once in motion, tend by considerable energy to remain in motion, the duplex pump by this peculiar delayed action has been found to be well suited.

It will be found that for complete uncovering of port, and motion divisible into thirds as described, the travel of the valve stem should be three times the width of port, or $3 \times \frac{7}{8}$ inch = $2\frac{5}{8}$ inches. A little more than this is allowed, and the travel made $2\frac{7}{8}$ inches in this case. Referring to Plate C, this distance is laid off as shown by the two limiting vertical lines across the line of the valve stem, the central vertical line of mid-position being drawn. The problem then is to find such centers for the rocker arms that the travel of the piston-rod spool will, through proper leverage, produce travel of the valve stem between these two vertical lines. This can readily be done by a few trials, the only requirement for this case being that the extremes of the arc of swing of both piston-rod lever and rocker arm shall be equally above and below the center of piston rod and valve stem respectively. The greatest possible travel of the piston-rod spool, $12\frac{1}{2}$ inches, is usually laid out in this case, not the nominal 12 inches.

From this layout the lengths of the levers and arms may be scaled off for the detail drawing, also the location of the rocker-arm centers. The student has the former given him on Plate K, but the latter, which is necessary for the development of Plate L, must be determined by his own layout. Plate D must also be



VALVE MOTION DET.
16-83-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORROSION TECH.
BOSTON - MASS.
SCALE - 8:1

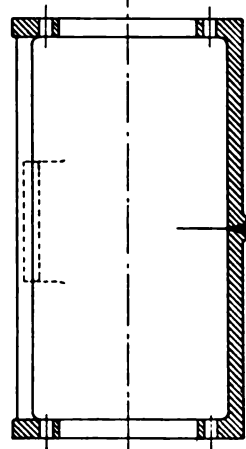
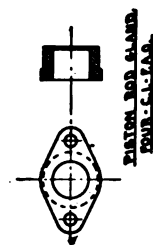
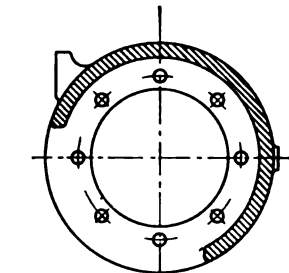
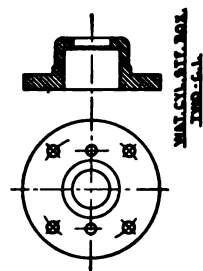
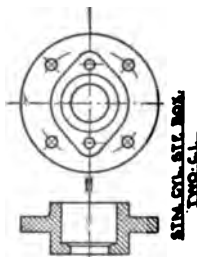
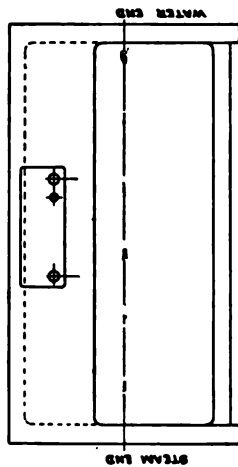
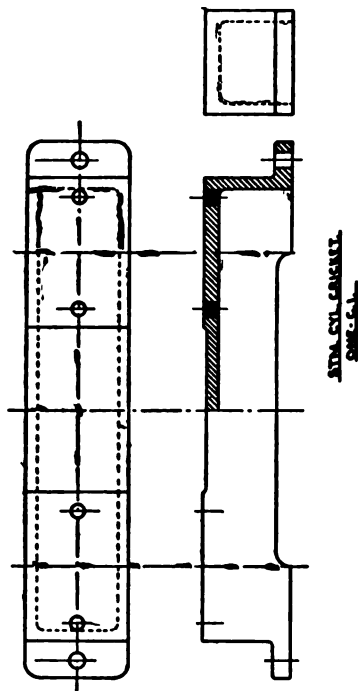
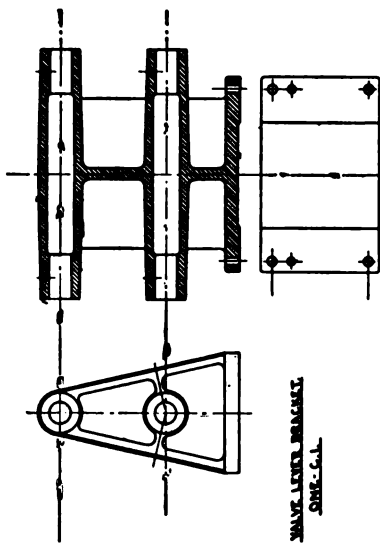
laid out before developing the cross-section of the valve bracket.

The design of stuffing boxes for both steam and water ends, and the length of the yoke, should be determined next. A safe method of assuming clearance between the spool and the gland studs at the end of the stroke, is to imagine that the gland stud nuts have accidentally worked off the studs, so that they are about to drop. They are thus shown by dotted lines on Plate C. A good clearance, say $\frac{1}{4}$ inch to $\frac{1}{2}$ inch, is then allowed, and the gland drawn in. The length of the gland is determined by the number of rings of packing necessary in the stuffing box; it is usually provided that the gland may compress the packing to about one-half its original depth before bringing up against the face of the box. Packing $\frac{5}{8}$ inch square will do for this size of piston rod, hence the faces of the yoke are easily determined, and its detail, with the stuffing boxes, proceeded with as on Plate L. The length of yoke may be brought to an even figure; and proceeding on the above plan the length can be conveniently made in even inches without any fractions; viz., 28 inches.

It will be noticed that the stuffing-box flanges serve to center the yoke in line with the steam and water cylinders. This is a desirable feature of construction, and forms a simple and easy method for lining up the steam and water ends.

Plate K. Valve Motion Details. The piston-rod levers on this plate are specified to be steel forgings. Forgings of this kind are expensive, but are light, neat and reliable for the important service which they have to perform. Castings, whether steel or iron, are much cheaper, and perhaps more commonly used for this detail. When sound they are equally serviceable, though of more clumsy proportions; but the danger in castings of this form is the existence of hidden flaws or pockets, which frequently occur at the points where the hub or the fork joins the arm. These flaws cannot be readily detected from the outside, and breakage may occur at some critical time, when the disability of the pump may be a serious matter.

The use of shade lines is illustrated on this plate. The increased artistic effect is noticeable, but it would seem that absolute clearness would still exist, even if shade lines were not used.



YOKES, STE. BOXES, BKT. ETC.
FOR 6-12 IN. DUPLEX PUMP.
AMERICAN SCHOOL OF
ENGINEERING.
BOSTON, MASS.
SCALE: 1/2".

YOKES.
ONE C.L. - R.H. 10 INCHES.
ONE C.L. - L.H.

It will be noticed that on the detail of the "link pin" two of the dimensions have a short "wavy" line beneath the figures. This is one of the several ways of indicating that the dimension is "out of scale." Some draftsmen use a straight dash beneath the figure; some draw a circle about it; some print after the figure, "out of scale." Although workmen are not allowed to scale drawings, but are required to "work to figures only," yet for general safety's sake, and for the sake of the draftsmen who consult the drawings frequently, attention must be called to any variation of the figure from the measured distance on the drawing. Nothing makes a workman, or any one else who reads a shop drawing, lose confidence in it more quickly than to discover that it does not "scale"; but when no indication exists that the draftsman himself is aware of it, then every dimension is viewed with doubt and hesitation, and the drawing becomes practically worthless.

Dimensions seldom should be out of scale; but if they are, through error or necessary change, a carefully worded note should be added.

Molding and Machining. No special features of molding or machining are noteworthy on Plate K.

Plate L. Yoke, Stuffing-boxes, Bracket, etc. Having worked up the layouts of Plates C and D, the student has enough information to proceed with Plate L. This, like Plate G, is without dimensions, the student's work being to make the drawing and fill in the necessary shop data.

The valve-lever bracket is bolted down to its lug on the yoke through holes larger than the bolt, thus permitting slight adjustment. When the proper location is determined, the bracket is positively fixed in position by two dowels, $\frac{1}{4}$ inch in diameter. The holes in both bracket and yoke are drilled through both pieces at the same operation. This very common method of fixing bolted parts of machinery in absolute position not only assures firmness, but also in case of removal, permits the part to be readily and positively replaced in its exact original position.

If possible, the steam cylinder cricket should be of such height that the stone or brick work upon which it rests shall be at the same level as that beneath the water cylinder. The tapped

holes in the top surface receive bolts from the cylinder foot. These bolts are often used only for shipping purposes, the cylinder foot when the pump is set up being allowed to slide freely on the cricket, thus permitting free expansion and contraction. In such cases the water end is rigidly fastened to the foundation by holding down bolts.

Molding and Machining. The valve lever-bracket would most naturally be molded with the axes of the shafts vertical, the parting line of the mold being the center line of the middle web. This makes quite a long "draw" for the shaft bosses, but the ample taper on the outside overcomes this difficulty. The space between the side webs leaves its own core. The shaft cores stand on end in the mold, which is the best position for strength and stability.

Another method is to have the parting line of the mold on the vertical center line of the bracket, as shown in the end view. In this case the bracket would be cast on its side, and cores must be set for each side of the middle web. The shaft cores are set as easily as before, but in this case lie flat. As with the steam chest, each method has its advantages, which depend largely upon existing conditions. As cored work is generally avoided whenever possible, the first method would probably be chosen.

The shaft bosses are "chamber-cored," to save labor in boring, the bearing surface for the shaft being only a short distance at the ends. The chamber-core diameter should be enough larger than the shaft so that by no possibility can the cutter run into the rough scale, even if the hole be bored slightly out of line. If it should do this, the labor of caring for the cutters more than offsets the attempted saving of labor.

The yoke is simply a barrel open at each end, and with a piece cut out of its side. The inside evidently must be cored out, and the core is satisfactorily supported at the ends on its horizontal axis. The parting line of the mold may be either the vertical or horizontal axis of the end view, the only difference being that in one case the ledge for the valve bracket will "draw," and in the other case it must be loose on the pattern and "pulled in" after the main pattern is drawn.

The cricket and stuffing boxes present no difficulties. The

bore of the stuffing boxes and glands should be from $\frac{1}{8}$ inch to $\frac{1}{16}$ inch larger than the rod, to allow the fit to be entirely between the rod and the packing.

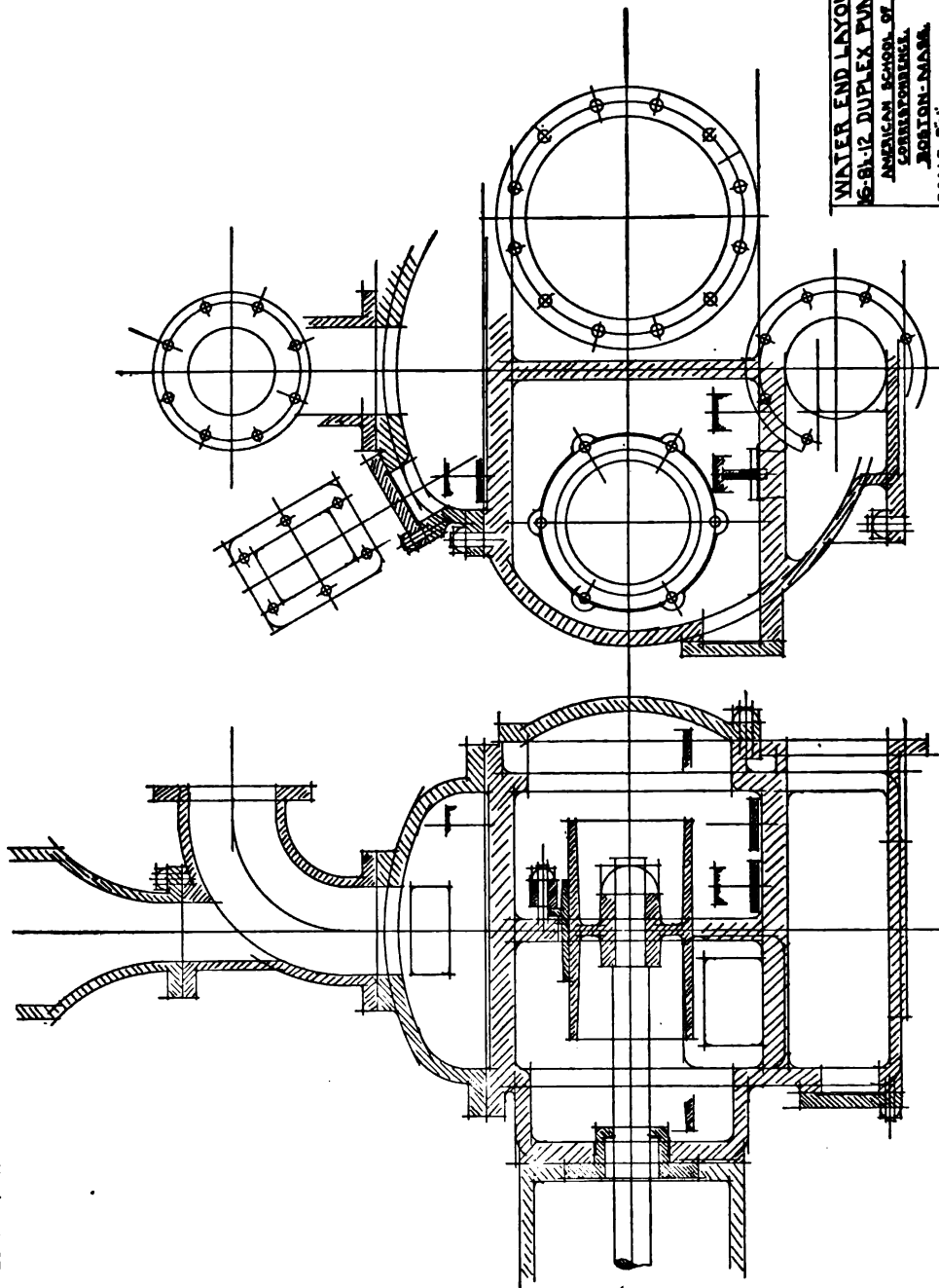
The horizontal boring machine with a double facing head is adapted to boring and facing the yoke flanges. The drilling is accomplished as before by templet or jig.

Attention is called to the tapped holes for oil or grease cups on the valve-lever bracket. The holes on the lower boss cannot be drilled strictly as shown, because the drill shank will not clear the upper boss. They should be swung around the boss at such an angle as will allow the drill to clear. This is a good instance of the common error of drawing details which cannot be made, and constant watch must be kept to avoid such mistakes.

Plate B. Water End Layout. As in the preceding work, Plates H and I being given in full detail offer a good start for the development of the water cylinder, which is the purpose of Plate B. As before, work should begin at the inside and progress outwards. Thus the piston rod with its nut should be drawn first, the hub of the plunger built around it, then the plunger barrel, the bushing, and ring to clamp the bushing. The limits of the plunger travel should be sketched in, and the valve outline shown in order to determine clearances. The progress of Plate B is on exactly the same basis as that stated in detail for the steam cylinder layout; hence it need not be repeated.

The points controlling the design of the water end must, however, be studied to enable the student to work intelligently. The fit of the rod into the plunger hub is loose, $\frac{1}{16}$ -inch play being allowed, in order to permit the plunger to be guided solely by its bushing, and thus be independent of any change of alignment of the piston rod.

The relative length of plunger and bushing should allow the end of the plunger to overrun the edge of the bushing at the termination of the stroke, to prevent the formation of a shoulder. The bushing is made of brass because of the better bearing of the two dissimilar metals, brass and iron. Of course there is no lubrication except the water, and the dissimilar metals tend to "cut" less than if both were alike. The brass bushing also prevents the plunger from "rusting in" in case of long periods of



WATER END LAYOUT
16-81-12 DUPLEX PUMP
AMERICAN SCHOOL OF
CORROSION-ENG.
BOSTON-MASS.
SCALE: 3/4"

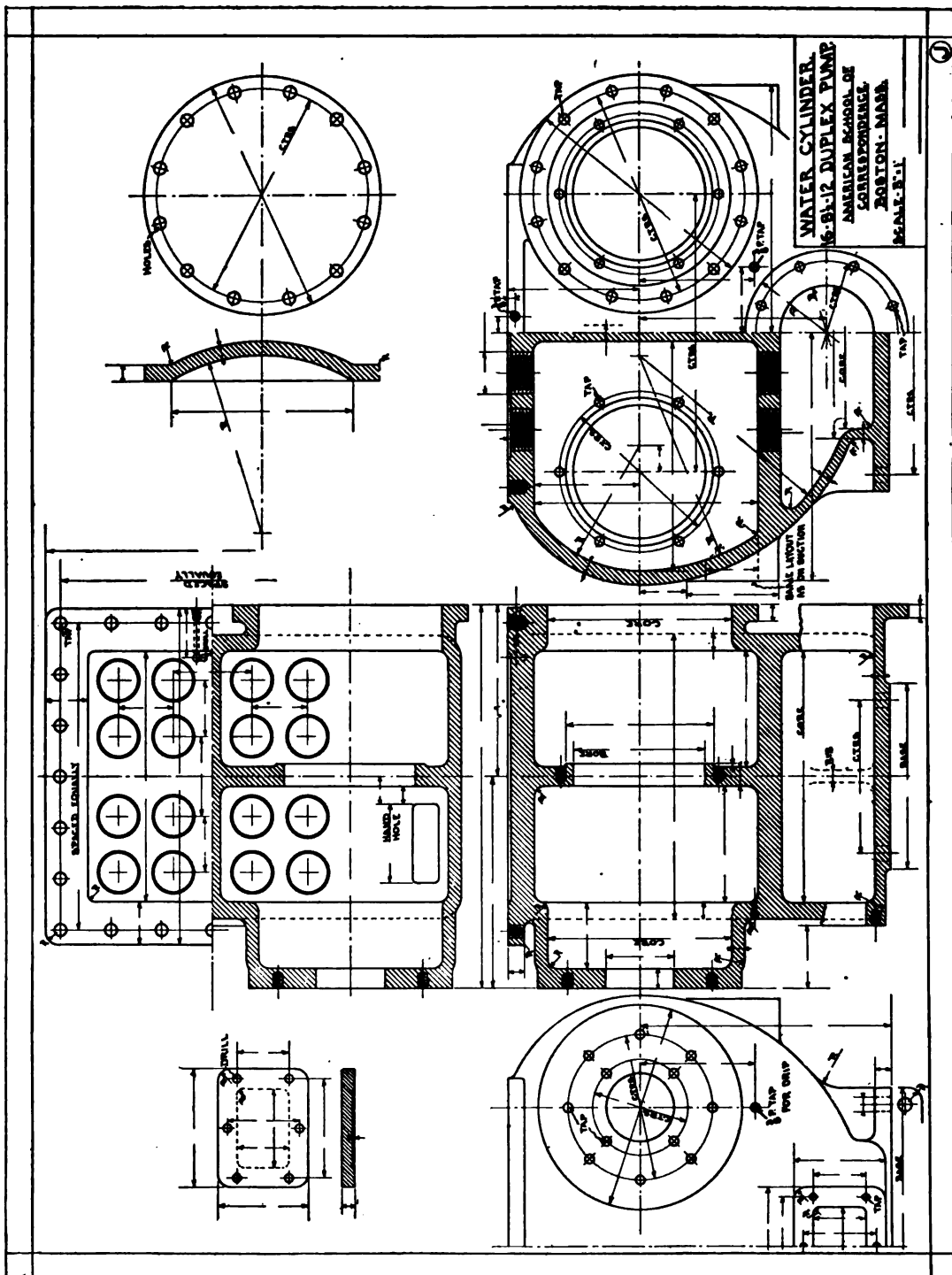
disuse. The bushing being of expensive material is made as light as possible, hence it has no stiffness of its own. Therefore it is reinforced by a deep cast-iron ring, which also takes the bolts and clamps the bushing tightly to its ground seat. These stud bolts are usually made of "tobin bronze," a rust-proof material, possessing strength almost as great as that of steel. This arrangement permits ready removal of the bushing when necessary.

As the parts of the common pump valve illustrated in detail on Plate H must be often replaced during service of the pump, provision must be made for unscrewing the stem and substituting a new one. This must be done through the hand holes provided on the cylinder. The lower valve deck must be located so that the inner valves when unscrewed will not strike the clamp ring. As shown in Plate B the clearance is pretty small, almost too small, but as it affects only two valves, it will probably cause no inconvenience. No hand holes are necessary for the end chambers, as access to the valves is had by removing the outer heads. The upper deck may be placed at a height giving sufficient clearance to allow the upper nuts of the clamp ring to be unscrewed with a socket wrench from the end of the pump. These decks are subjected to a severe pounding from the pulsations of the pump, and should be amply strong; $1\frac{3}{4}$ inches is deemed thick enough for this case.

The middle transverse wall may be $1\frac{1}{2}$ inches thick and the middle longitudinal wall a little thinner, about $1\frac{1}{4}$ inches. With high pressures these walls, being flat surfaces and the valve decks likewise, are likely to fracture under the heavy pounding. To avoid making them excessively heavy they are often strongly ribbed, either on the inside or outside, usually the former.

The curving side walls are of better form to withstand pressure, and need not be as thick, 1 inch being sufficient. This can be decreased to $\frac{3}{4}$ inch in the suction passage below the deck, where little pressure exists.

The outer head is also considered strong enough at 1 inch thickness, on account of its curved shape. It requires $\frac{7}{8}$ -inch studs. Studs are preferred to tap bolts in this case, as in all other similar cases, on account of the frequent unscrewing of the nuts for purpose of removal. One or two unscrewings of a tap bolt in cast



iron will destroy the tightness of the thread, while the stud, being steel, stands the wear better.

The valve seats are taper screwed into the deck; they are sometimes forced in on a plain taper fit. They are located as closely as strength of the deck between the holes will permit. It is not well to place the edge of the valve closer than $\frac{1}{2}$ inch from the cylinder walls. The valve holes in the lower deck should be in line, or nearly so, with the holes in the upper deck, in order to allow the shank of the mill to pass through when milling the lower holes.

The suction opening is 7 inches in diameter, $12\frac{1}{2}$ -inch flange, $10\frac{1}{2}$ -inch bolt circle, $\frac{3}{4}$ -inch tapped holes.

By means of the hand hole at the end of the suction passage, any dirt which may have been brought in through the suction pipe may be removed.

The water cylinder cap, discharge ell and air chamber may be laid out from the detail Plate I, and the student must do this to see that the parts actually go together properly.

With the foregoing discussion the student should be able to produce Plate B, which is the preliminary step to the detail drawing of the water cylinder as shown on Plate J.

Plate J. Water Cylinder. The water cylinder is, perhaps, the most complicated detail that the student will meet in this set of plates. Fundamentally, it is simply a box with curved sides, divided by the several walls into five compartments, each of which communicates with the outside by a round nozzle or flange. If this basic idea be kept constantly in mind, the student will have no trouble in building up the detailed design.

This fundamental conception of a complicated piece is a very important idea, and should be developed carefully by the student. It is one of the great secrets of good design, both from an artistic and a commercial standpoint. We often see a machine which seems to begin anywhere and end nowhere; it appears to be a miscellaneous collection of bosses, lugs, ribs and flanges. There is no general prevailing shape to the structure, no harmony of the lines. This is because the designer, if he may be so called, did not have the fundamental notion of shape, to which all minor details should have been subordinated. He simply grouped

parts together, without considering the fundamental structure.

In this water cylinder the box is the basic part of the structure, and its lines must be first developed; they should be designed to convey a smooth, regular and consistent surface to the eye. Then the nozzles and flanges may be added as subordinate parts; they will merely interrupt, but not destroy, the prevailing outline of the box. The dotted lines in the cross-section views of Plate J show the general shape behind and beneath the nozzles.

The hand holes are the same as on Plate I, and the detail of the cover should specify the number required for both places.

Provision for draining the four chambers of the water cylinder is made by the $\frac{3}{8}$ -inch pipe tap holes at the lower deck, and the cap, likewise, by the single hole at the upper deck. Drip cocks are screwed into these holes.

The holding-down bolts should not be less than 1 inch diameter; $1\frac{1}{4}$ inch would perhaps be better; and the holes in the foot should be drilled at least $\frac{1}{8}$ inch large.

Dimensions. It will be noticed that this plate has dimension lines, but no figures. This is because the cylinder is rather difficult to figure, and it is desired to guide the student in arrangement of the figures without lessening the benefit of his study of them. Special attention should be paid to this feature of the plate. Notice that although space for dimensions is restricted, a clear opening is always found for the figures; and when one view seems to offer no space for a figure, another view gives the desired opportunity.

No finish marks or titles are shown on this plate, these being left entirely to the student for insertion.

Molding. The centers of the curves for the sides being on the main horizontal axis of the nozzles, the cylinder, if molded to be cast vertically as shown, will draw readily both ways from this line. The exceptions to this easy draw are the foot, suction nozzle and flange, and hand-hole boss. On account of the inside of the cylinder being cored, these pieces if made loose on the pattern have ample space to be "pulled in" after the main pattern is withdrawn.

The suction passage below the deck communicates with the main core through the valve holes, hence it may be supported

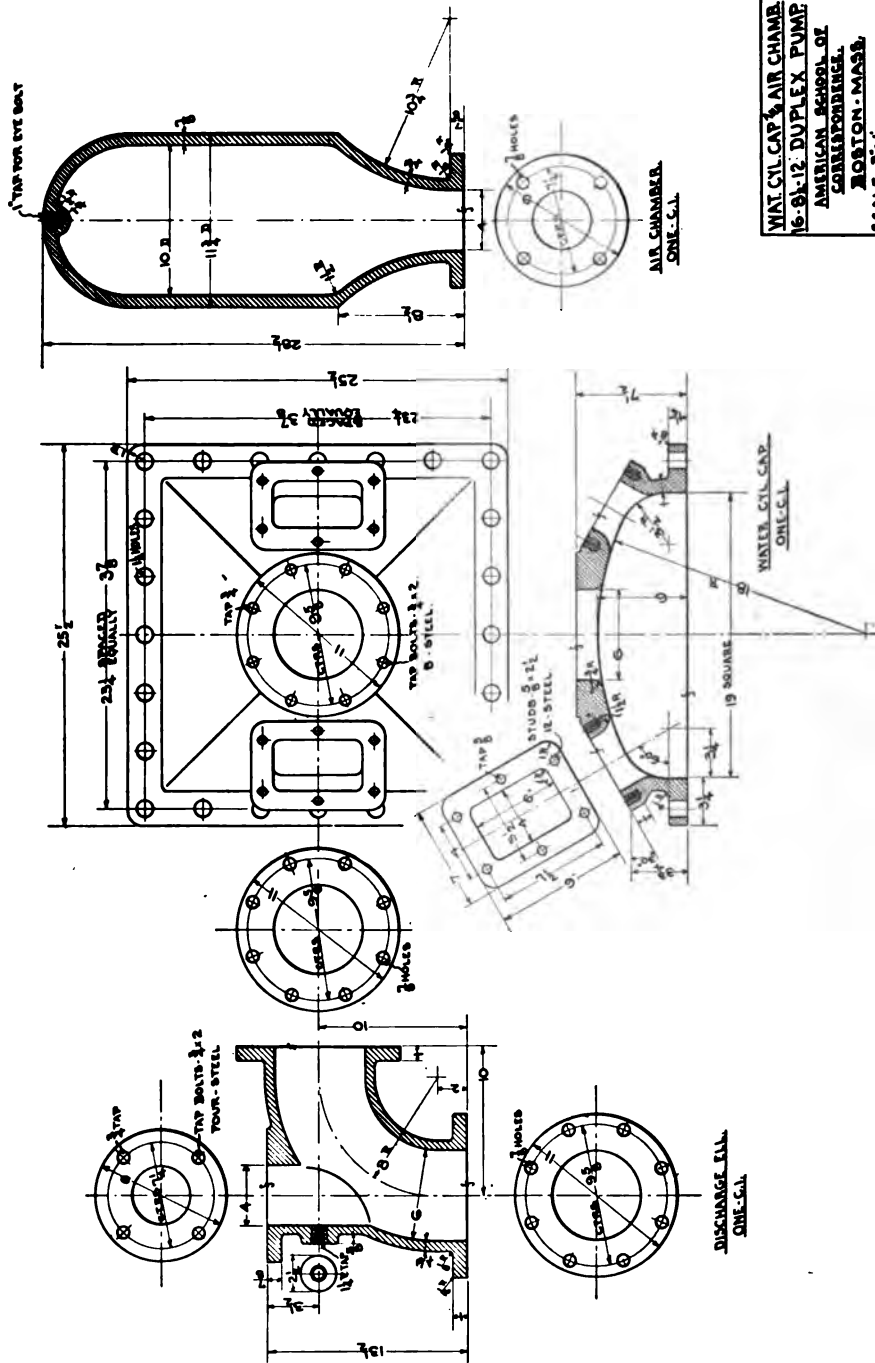
from the main core. This involves some difficulty, however. If a three-part flask be used, and another parting established at the center of the suction flange, in addition to the previous one, the problem becomes much simplified.

It is desirable to make the four chambers of the cylinder alike in general proportions. It is then possible to make a single core-box, and by the use of loose pieces change the length of the nozzle cores and transpose from right to left, thus saving labor on the pattern. This, however, multiplies the loose pieces on the pattern. The many pieces are likely to become lost and make frequent repair necessary. Hence it is not always wise to use a single core box too much, and good judgment is required to fix the limit.

Machining. Special double horizontal boring machines are now in common use for such cases as this water cylinder. The centers are made adjustable, so that within limits any distance between piston-rod centers can be met. The advantages of double boring are, of course, most obvious for a considerable number of duplicate cylinders.

It will be noticed that the face of the suction flange is carried out flush with the cylinder head face. This affords opportunity for finishing all the end surfaces at a single setting of the tool, whether the work be done on the rotary or reciprocating planer. This same point might have been observed on the small hand-hole boss at the other end of the cylinder, but the advantage gained did not seem to warrant extending the "reach" through the hand hole.

Plate I. Water Cylinder, Cap and Air Chamber. For a water cylinder cap of this size, the most difficult problem is to find room for the hand-hole bosses. A hand hole 4 inches $\times$ 6 inches is about as small as can be used, and this calls for a flange at least 7 inches $\times$ 9 inches. These are the proportions shown on the plate, and since the boss overhangs the bolts in the main-cap flange, it must be cut away underneath to clear the nuts. If three stud bolts are used on each side, this overhang also requires that the nut be "fed on"; that is, screwed on little by little as the end of the stud protrudes above the flange when the cap is being lowered into place. This is an awkward process, but is sometimes necessary.



WAT. CYL. CAP. & AIR CHAMBER
16-8 1/2" DUPLEX PUMP
AMERICAN SCHOOL OF
CORRESPONDENCE
BOSTON - MASS.
SCALE - 3" = 1"

1

The discharge ell should have an easy bend; usually the radius is somewhat more than the outside diameter of the pipe, in this case 50 per cent greater. It is customary on this piece to provide an opening for the attachment of a relief valve as shown, $1\frac{1}{4}$ -inch pipe tap. This valve can be set to open at a desired pressure, so that the water end may be relieved in case of accidental excessive pressure.

The air chamber provides an air cushion for the water to make the delivery more constant, and take the shock which would otherwise come with hammer-like force and full intensity upon the cylinder. Being placed at the highest point of the water end, air will naturally tend to collect in the air chamber and keep it charged. In some cases, however, a special charging device is necessary.

Molding and Machining. The hand holes being at an angle will not "draw." Hence cores must be set for these openings at least, and it may be desirable to core out the whole inside of the cap for the sake of keeping the pattern in good shape by making it solid. Otherwise it is easy to let it leave its own core.

The overhang of the hand-hole bosses requires loose pieces for the overhanging part. They are "pulled" in after the pattern is drawn.

The molding and machining which are further required on details of Plate I are simple, and require no special discussion.

Plate H. Plunger and Valve Details. This plate is noticeable for illustrating a method of drawing details not used elsewhere in this set of plates. On the other plates each piece is separately detailed. On Plate H the details of the valve, cover, seat, stem and spring are shown assembled, and dimensioned without separation. This is an allowable method when clearness is not sacrificed, but it is usually found desirable only with simple construction. It concentrates parts on the drawing, and probably saves some time, besides showing the workman just how the parts go together. The only test which the student need to apply in this, as in any method of detailing, is the test for absolute clearness.

It is believed in the case of the valve as shown that the details are completely illustrated without sacrificing clearness. Special care in putting in dimensions is of necessity required.

The valve stem can be unscrewed either with a socket wrench on the inside or an ordinary fork wrench on the outside.

The seat, after being screwed to position in the deck, is often faced off, to true up any distortion caused by screwing in.

The valve itself, of rubber, can be bought of any desired grade of hardness. The specification for any given set of valves depend upon the quality of the water, the pressure and the general service of the pump.

Molding and Machining. By reason of the simple nature of the parts on this plate, the molding and machining is left entirely to the original consideration of the student.

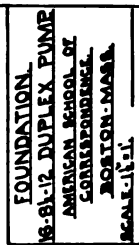
Plate M. Foundation. Pumps are often set directly upon a foundation of brick, but it makes a better job to bed stones, with surfaces dressed plane and true, into the main foundation, and rest the pump feet upon these stones. The simplest form of holding down bolts are shown on Plate M, a plain hook at the lower end, pulling up against a flat cast-iron plate, to distribute the pressure into the brickwork. These plates are of course bedded, and the bolts set as the foundation is built up. As the subsequent courses are laid some little space is left around the bolts, which may be afterwards filled with cement, thus making the bolts rigid with the foundation.

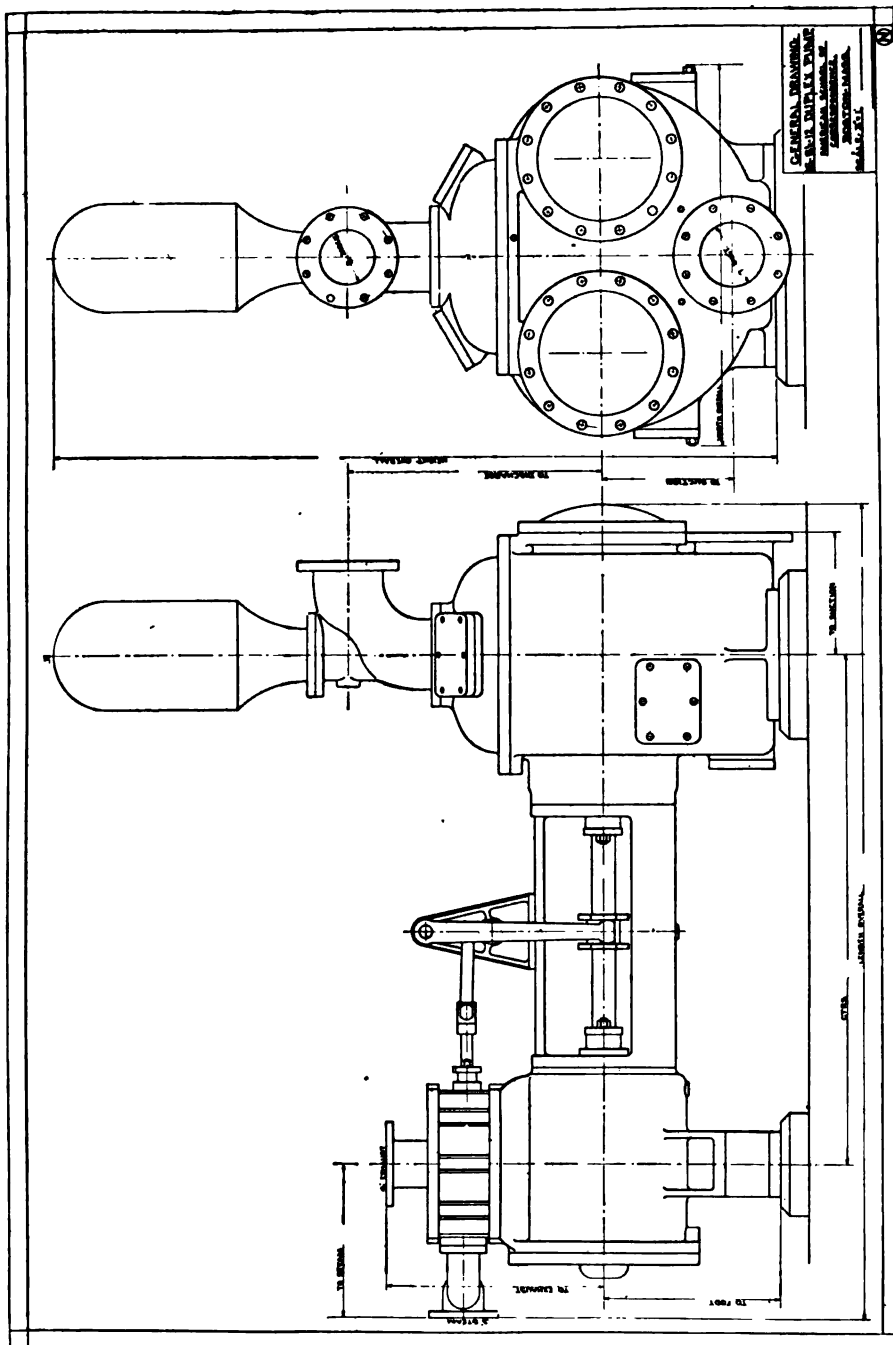
The water end of the foundation has no batter, because the suction pipe often drops vertically down from the end of the pump, and clearance is therefore necessary.

The floor line is placed 4 inches above the brickwork, to allow for the usual 1-inch top floor and 2-inch plank beneath, and still have a space left for shims to level the floor.

Plate N. General Drawing. This is an example of a plain, everyday shop drawing, to show the relation of parts and the extreme space occupied by the pump. A great deal of time can be needlessly wasted in producing a drawing of this character, by trying to make too faithful a picture. For example: If all the bolt heads were put in, it is safe to say that several hours' extra time would be required for this one item alone. But the drawing would be no better for shop use. Hence all bolt heads and nuts have been left out, except when necessary to show clearance.

Shade lines have been put on for no special reason except





that if they are desirable on any drawing they are especially desirable on a general drawing, where one part overlaps another, as they make it easier to pick out and separate one surface from another. Some lines are shaded in this drawing which are not strictly sharp edges. It is held, however, that the rounding of a corner ought not to destroy its character as an edge casting a shadow, and such lines are treated accordingly.

An assembled or general drawing of this character should be laid out strictly from the dimensions shown by the details. It thus serves a valuable purpose in checking up figures, and showing whether or not the parts will go together. The method or character of the work in no respect differs from that suggested for the detail drawings.

If a scale of 3 inches = 1 foot be used, the size of sheet must be 24 inches $\times$ 36 inches. The student, however, will perhaps find it easier to use a scale of $1\frac{1}{2}$ inches = 1 foot, in which case the ordinary size, 18 inches $\times$ 24 inches, will suffice. For such a small scale it will be found undesirable to attempt to put in any very small fillets and corners, although those that can be readily handled by the ordinary bow pen ought not to be omitted. As a matter of fact, the expert draftsman either leaves the corners sharp, as suggested, or puts in the smallest curves freehand.

Order Sheets. Any set of drawings is incomplete unless in connection with it a statement is made in tabular form of the complete make-up of the machine. An infinite variety of ways exists for making the specifications. Sometimes the tabulated data are placed on the general drawing. Most often, however, printed blanks are provided, usually of bond paper, arranged with special reference to the individual shop system and methods of handling work; these blanks are filled in by the draftsman, indexed and filed as a part of the set of drawings. They can be blue printed for use in the shops the same as a drawing. From these sheets stock is ordered, checked off, and watched in its process of manufacture.

Order sheets are indispensable in any well-ordered shop. Hence they are illustrated on pages 59, 60, 61 and 62 as the final step in the set of pump drawings. They are made as simple as possible, and are not intended to fit any special shop system. As

previously stated, the exact form and method of classification can be determined only when the shop conditions are known.

The student, having carefully followed through the preceding pages, must not think that he is master of pump construction, for even the type illustrated has been but touched upon. The object of the detailed discussion is to get the student in close touch with the spirit of construction, to make his drawings real serious work. It is hoped that the student will work just as though a machine were to be built from his drawings, and built to sell at a profit. Only in this way can advanced work in mechanical drawing be of benefit to him, for after becoming expert in the use of the instruments, no other advance is possible except advance in *thought*.

DATE.
MAY 20, 1902.

AMERICAN SCHOOL OF CORRESPONDENCE
AT
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.

TYPE.
INSIDE PLUNGER.

LIST OF CASTINGS

FOR

16-81-12 DUPLEX PUMP.

No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
2	Steam Cylinder	G		C. I.	R. & L.
2	Steam Cylinder Head	G		C. I.	
2	Steam Chest	F		C. I.	
2	Steam Chest Cover	F		C. I.	
2	Slide Valve	F		C. I.	
1	Steam Pipe	F		C. I.	
1	Exhaust Tee	F		C. I.	
2	Valve Steam Gland	F		C. I.	
2	Piston	E		C. I.	
8	Piston Pipe Plug, 1½"	E		C. I.	
4	Piston Packing Ring	E		C. I.	
2	Spool	E		C. I.	
1	Steam Cylinder Cricket	L		C. I.	
2	Steam Cylinder Stuffing Box	L		C. I.	
2	Water Cylinder Stuffing Box	L		C. I.	
4	Piston Rod Gland	L		C. I.	
1	Valve Lever Bracket	L		C. I.	
2	Yoke	L		C. I.	R. & L.
1	Short Rocker Arm	K		C. I.	
1	Long Rocker Arm	K		C. I.	
2	Valve Stem Link	K		C. I.	
1	Water Cylinder	J		C. I.	
2	Water Cylinder Head	J		C. I.	
5	Hand Hole Cover	J		C. I.	
1	Water Cylinder Cap	I		C. I.	
1	Air Chamber	I		C. I.	
1	Discharge Ell	I		C. I.	
2	Plunger	H		C. I.	
2	Plunger Bushing	H		Brass	
2	Clamp Ring	H		C. I.	
32	Valve Stem	H		Brass	
32	Valve Cover	H		Brass	
32	Valve Seat	H		Brass	
6	Foundation Plate	M		C. I.	

DATE.
MAY 20, 1902.

AMERICAN SCHOOL OF CORRESPONDENCE
AT
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.

TYPE.
INSIDE PLUNGER.

LIST OF STEEL AND MISCELLANEOUS PARTS

FOR

16-81-12 DUPLEX PUMP.

No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
2	Valve Steam Head	E		St.	Drop Forging.
2	Piston Rod	E		C. R. S.	
2	Valve Stem	E		St.	
1	Long P. R. Lever	K		St.	Forging
1	Short P. R. Lever	K		St.	Forging
1	Upper Rocker Shaft	K		St.	
1	Lower Rocker Shaft	K		St.	
2	Rocker Arm Pin	K		St.	
2	Link Pin	K		St.	
1	Long P. R. Lever Key	K		St.	Drop Forging
1	Short P. R. Lever Key	K		St.	Drop Forging
2	Rocker Arm Key	K		St.	Drop Forging
32	Valve Spring	H		Brass wire	Spring Temper
32	Valve	H		Rubber	Medium

DATE.
MAY 20, 1902.

AMERICAN SCHOOL OF CORRESPONDENCE
AT
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.

TYPE.
INSIDE PLUNGER.

LIST OF BOLTS, NUTS AND PINS

FOR

16-8½-12 DUPLEX PUMP.

No. wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
12	Cylinder Head Stud $\frac{7}{8} \times 3\frac{1}{2}$	G		St.	
20	Steam Chest Stud $\frac{3}{4} \times 8\frac{1}{2}$	G		St.	
4	Valve Stem Gland Stud $\frac{5}{8} \times 4\frac{1}{2}$	F		St.	
8	Piston Rod Gland Stud $\frac{3}{4} \times 4$	L		St.	
24	Water Cylinder Head Stud $\frac{7}{8} \times 3\frac{1}{2}$	J		St.	
12	Clamp Ring Stud $\frac{3}{4} \times 4\frac{1}{2}$	J		Tobin bz.	
24	Water Cylinder Cap Stud $1 \times 3\frac{1}{2}$	J		St.	
18	Hand Hole Cover Stud $\frac{5}{8} \times 2\frac{1}{2}$	J		St.	
12	Hand Hole Cover Stud $\frac{5}{8} \times 2\frac{1}{2}$	I		St.	
8	Exhaust Tee Tap Bolt $\frac{5}{8} \times 1\frac{1}{2}$	G		St.	
16	Yoke Tap Bolt $\frac{3}{4} \times 2$	G		St.	
8	Steam Cyl. Stf. Box Tap Bolt $\frac{3}{4} \times 1\frac{1}{2}$	G		St.	
8	Steam Pipe Tap Bolt $\frac{5}{8} \times 1\frac{1}{2}$	F		St.	
4	Valve Lever Bracket Tap Bolt $\frac{5}{8} \times 1\frac{1}{2}$	F		St.	
4	Steam Cyl. Cricket Tap Bolt $1 \times 2\frac{1}{2}$	F		St.	
16	Yoke Tap Bolt $\frac{3}{4} \times 2$	J		St.	
8	Water Cyl. Stf. Box Tap Bolt $\frac{3}{4} \times 1\frac{1}{2}$	J		St.	
8	Discharge Ell Tap Bolt $\frac{3}{4} \times 2$	I		St.	
4	Air Chamber Tap Bolt $\frac{3}{4} \times 2$	I		St.	
2	Hook Bolt (special) $1 \times 3' - 11''$	M		St.	
4	Hook Bolt (special) $1\frac{1}{2} \times 3' - 11''$	M		St.	
1	Eye Bolt Standard $1''$	I		St.	
34	Standard Nut $\frac{5}{8}$			St.	
44	Standard Nut $\frac{3}{4}$			St.	
36	Standard Nut $\frac{7}{8}$			St.	
26	Standard Nut 1			St.	
4	Standard Nut $1\frac{1}{2}$			St.	
4	Standard Nut 2			St.	
8	Special Valve Stem Nut 1			St.	$\frac{1}{2}$ Thick
4	Piston Rod Split Pin $\frac{1}{2} \times 2$	E		St.	
2	Spool Taper Pin No. 10 Morse Taper	E		St.	4" long
4	Valve Bracket Dowel Pin $\frac{1}{2} \times 2$	L		St.	

DATE.
MAY 20, 1902.

AMERICAN SCHOOL OF CORRESPONDENCE
AT
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.

TYPE.
INSIDE PLUNGER.

LIST OF SPECIAL FITTINGS, WRENCHES, ETC.

FOR

16-81-12 DUPLEX PUMP.

No. Wanted.	Name.	Drawing No.	Patt. or Piece No.	Material.	Remarks.
4	Drip Cock $\frac{1}{4}$ "	G			
1	Drip Cock $\frac{1}{4}$ "	F			
2	Drip Cock $\frac{1}{4}$ "	L			
4	Oil Cup $\frac{1}{4}$ "	L			
5	Drip Cock $\frac{3}{8}$ "	J			
1	Relief Valve $1\frac{1}{4}$ "	I			175 lbs. pressure
1	Standard Fork Wrench $\frac{3}{8}$ "				
1	Standard Fork Wrench $\frac{1}{2}$ "				
1	Standard Fork Wrench $\frac{7}{8}$ "				
1	Standard Fork Wrench 1"				
1	Socket Wrench $\frac{3}{4}$ "				12" handle
1	Valve Stem Fork Wrench				
1	Valve Stem Socket Wrench				

PLATES.

The plates of Part VI (A to N, inclusive,) are so arranged and described that the complete set may be made by the student. In case of insufficient time, the following short examination is prescribed. The student in any case should read carefully all the text, and follow the discussion of all the plates, whether or not actually produced by him.

PLATE XXV.

Reproduce Plate E (page 32), putting on shade lines. Size of plate to be 18 inches $\times$ 24 inches, trimmed, with border $\frac{1}{2}$ inch from edge; size within border line, 17 inches $\times$ 23 inches.

PLATE XXVI.

Make steam end layout, Plate A (page 10). This is to be done accurately *in pencil*. Size same as Plate XXV.

PLATE XXVII.

Make drawing of steam cylinder, Plate G (page 18), complete, with finish marks and dimensions. Do not put on shade lines.

PLATE XXVIII.

Draw valve motion layout, Plate C (page 36). This plate also is to be done accurately *in pencil*.

PLATE XXIX.

Make rough freehand sketches in pencil of parts on Plate L (page 42), putting on finish marks and dimensions. Use a medium pencil, and make sheet of regular size (18 inches $\times$ 24 inches). Arrangement to be similar to Plate L. Do not try to make the sketches to scale, but make them sufficiently complete so that detail drawings can be made from them.

PLATE XXX.

Make a tracing on tracing cloth of Plate E (page 32).

PLATE XXXI.

Make general drawing Plate N. Use scale of $1\frac{1}{2}" = 1'$, or $3" = 1'$.

PLATE XXXII (Optional).

Make drawing of water cylinder, Plate J (page 48).

GENERAL INDEX.

Reference Library Modern Engineering Practice.

IN TEN VOLUMES.



TITLES FOR SECTIONS.

VOLUME I.			Locomotive Boilers and Engines,		
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